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NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 7

Detection of Low-Current Short Circuits

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NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 7

Detection of Low-Current Short Circuits

NAVIN S. SAGAR
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Boston, Massachusetts

AREAS OF INTEREST

- Administration
- Maintenance
- Transportation Safety
- (Public Transit)
- (Rail Transportation)

RESEARCH SPONSORED BY THE URBAN MASS TRANSPORTATION ADMINISTRATION OF THE U.S. DEPARTMENT OF TRANSPORTATION

TRANSPORTATION RESEARCH BOARD
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WASHINGTON, D.C. DECEMBER 1984

NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one is which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services and (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance.

Research Programs for the NCTRP are developed annually by the Technical Steering Group, which identifies key problems, ranks them in order of priority, and establishes programs of projects for UMTA approval. Once approved, they are referred to the National Research Council for acceptance and administration through the Transportation Research Board.

Research projects addressing the problems referred from UMTA are defined by panels of experts established by the Board to provide technical guidance and counsel in the problem areas. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out by these agencies under contract to the National Reserch Council, and administration and surveillance of the contract work are the responsibilities of the National Research Council and Board.

The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

NCTRP REPORT 7

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, or the Urban Mass Transportation Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

Electric rail transit operations and safety personnel will find this report of interest and value with regard to the problem of detecting low-current short circuits. Although U.S. transit systems use relatively outdated low-current fault detecting devices, it appears that several more modern and effective devices in use in other countries could be adapted for use in this country. A pilot test program with a cooperating transit agency to demonstrate the applicability of such devices in the United States is recommended.

Devices presently in use by the rail transit industry can adequately detect and respond to overload fault currents. Detection of less than overload fault currents is particularly difficult because the characteristics of such currents resemble characteristics normally associated with train or power switching operations. Consequently, trains may continue to operate until the fault current becomes large enough to be detected by overload devices or until the fault results in smoke and fire activity. The latter is particularly hazardous in tunnel systems.

The objective of this research was to identify and provide preliminary evaluation of detection methods and equipment to enhance transit system safety through reliable detection of electrical faults that are not detected by circuit breaker overload protection. The Charles T. Main, Inc., researchers conducted an extensive survey of rail transit systems, electrical industry organizations, and electrical equipment suppliers worldwide to determine how the problem is currently being handled and to identify methods and equipment that may provide potential solutions.

Information collected on the consequences of low-current faults did not identify evidence of highly dangerous incidents. Reports indicated damage to facilities and equipment and incidents of localized smoke and fire. It appears that several types of low-current fault detection devices are in use in countries other than the United States that could be adapted for use by transit systems in this country. Field testing, in cooperation with an electric rail transit system, is recommended as the next appropriate step towards improved low-current fault detection.

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The research reported herein was performed under NCTRP Project 43-1 by Chas. T. Main, Inc., Engineers Power Division.

Mr. Navin S. Sagar, Lead Electrical Engineer, was the principal investigator. Harrison S. Campbell, a special consultant, was the co-principal investigator. Mr. E. Sherman participated in analysis and review. The work was performed under the overall supervision of Messrs. Robert W. Flugum and Anthony A. Kounelas.

The assistance of Messrs. Ron Sturland and L. Denning of General Electric Co. of England, as well as the staff of its local affiliation, English Electric Company of New York, is also gratefully acknowledged.

DETECTION OF LOW-CURRENT SHORT CIRCUITS

SUMMARY

The research results presented in this report are a product of a study that was carried out under NCTRP Project 43-1. The report presents the results of surveys performed of transit systems, equipment manufacturers, and suppliers in the United States and throughout the world concerning the problem of detecting low-current short circuits. On the basis of the responses from transit systems in 25 countries out of a total of 34 surveyed, it appears that a number of modern low-current fault-detection devices are in use in other countries that are not in common use in the United States. The majority of U.S. systems that responded seem to be using relatively outdated and less adequate low-current fault detection (LCFD) devices.

Some of the more promising solid state dielectric LCFD devices reported are BBC-Sécheron DDL line fault detectors and relay type PCC-67a detectors that are being used in traction power systems, but are claimed to detect on-board faults as well. Other challenging devices are an electronic rate-of-rise trip assembly and a pilot wire relaying scheme, also for use in traction power (TP) systems.

The most frequently used devices on-board cars include high speed circuit breakers (HSCB) working on the di/dt principle (rate-of-rise of current), fuses, overcurrent, overload, and differential devices. There were some reports of modifying the car control circuit for rapid detection and clearing of low-current faults on-board cars. Two responses reported on prototype devices developed are for ground fault and dynamic brake traction motor protection as well as for a heater fault detection system on-board cars. The responses describe numerous LCFD devices that are available in the market or are custom designed and used by the transit systems themselves. The majority of these devices are for use in traction power systems, and some are reported to be capable of detecting on-board faults.

Utilities and mines reported difficulty in detecting low-current short circuits. A thorough testing program and exhaustive efforts to seek LCFD solutions were reported by one utility company, and by a working group of the Institute of Electrical and Electronic Engineers (IEEE). A prototype electromechanical relay using both high and audio frequency superimposing techniques is under test by several utilities where performance is being carefully monitored.

Mine approaches include the use of discriminating circuit breakers as well as trolley wire protection schemes using a high frequency voltage superimposed on the trolley wire, along with undervoltage and current relays.

Some information on the consequences of low-current faults was obtained from the survey, although data on safety and hazard experience revealed little evidence of highly dangerous incidents. The reports included damage to the system facilities and rolling stock. Any undetected short circuit can possibly result in fire and smoke and hence the problem of LCFD is apparently an important concern to safety.

Actions that might be taken in this area include developing comprehensive guidelines for cost-benefit analysis, design and testing of LCFD devices for the transit systems, and participation in a pilot test program with a cooperating transit system to demonstrate the applicability of the devices reported in this study to U.S. systems. The report also includes a discussion of the various types of devices which can usefully be tested in a government or transit system sponsored program.

CHAPTER ONE

INTRODUCTION

RESEARCH OBJECTIVES AND PROBLEM STATEMENT

Research Objectives

When typical starting traction motor current characteristics are compared with the low level fault current characteristics, the profile of the latter is uniformly lower, mainly due to the system short circuit impedance. As a result, such faults are often not detected, with potentially serious consequences to safety and operation.

NCTRP Project 43-1 had as its objectives the determination of the causes and/or situations resulting in low level fault currents and the most commonly applied methods of detecting and protecting against them. These objectives were to be accomplished by:

- Surveying transit agencies worldwide to learn about their experience.
- Surveying industry organizations and industries to learn if similar problems and solutions exist.
- Surveying of equipment suppliers to learn of their efforts and equipment offered for low-current fault detection.

On the basis of the information gathered in the surveys, the study was to identify and evaluate methods and equipment for improved detection of low-current faults which would result in enhancement of transit system safety in the United States.

Problem Statement

General Description

Short circuits or faults on many transit systems are difficult to detect because the short circuit current is no larger, if as large, as load currents arising in normal operations.

Low level faults may have time-current characteristics resembling those associated with the train starting or with power switching operations, which make them difficult to detect. Detection becomes even more difficult for remote faults as substation capacity and spacing between substations increases. Failure to detect such faults permits arcing, possibly resulting in fire and jeopardizing the safety of the riding public and operation of the system.

Devices presently in use in the traction power system and transit vehicles can adequately detect and clear fault currents due to overloads or heavy short circuits. The detection of fault currents of magnitude less than feeder breaker trip setting is the crest of the problem. Such faults are not frequent, but they may be extremely hazardous if they remain undetected when they occur.

Subsystems or components and situations that have been noted as being involved in low-current short-circuit problems include the following:

1. Faults involving transit vehicles.
    a. Car control system (cam or chopper).
    b. Dynamic rheostative braking system.
    c. Commutator motor.
    d. Motor-alternator set motor.
    e. Failure of internal component of auxiliary or HVAC system.
    f. Arcing while passing through a crossover.
    g. Cable to car body short.
    h. Relay to car body short.
    i. Arc from arc-chute to car body.
    j. Positive current collector shoe torn loose.
    k. Piece or component dragging and contacting third rail.
    l. Rubber tire blowout (for system with rubber tires).
2. Faults on the traction power and distribution system.
    a. Arcing faults in the dc cables at trackside sectionalizing switches or in manholes or cable vaults.
    b. Broken trolley wire in contact with car, running rails, or ground.
    c. Faults due to switching a utility company line feeding a traction power substation onto an already energized system.
    d. A foreign object causing arcing between the contact rail and ground (at a point remote from the substation).
    e. Arcing across a contact rail support insulator.
3. Conditions which increase the difficulty of detecting low-current faults.
    a. Transients caused by switching of equipment on utility high tension line.
    b. Crowding of trains per feeding section.
    c. Simultaneously accelerating trains in opposite directions in a feeding section closer to the substation.
4. Specific situations involving high impedance faults or arcing faults.
    a. Fault that developed and persisted between contact rail, cast iron tunnel liner and negative running rail which resulted in a 4-hour delay during morning rush hour.
    b. Fault involving contact rail and a base slab, scorching the subway wall and damaging a car body.

Parameters and Characteristics of Fault Currents

Fault current waveshape and magnitude depend on the effective resistance, R, and the effective reactance, X, of the circuit. These parameters are easy to calculate when the fault occurs near or at the substation. However, the magnitude and shape of the current resulting from a low level fault at a location remote from the substation depend on the additional R and X values of the circuit outside of the substation. The additional impedance includes resistance and reactance of contact rail or catenary section, negative return system, tracks and impedance bond, and track configurations. If the fault is of the arcing type, the arc impedance will also affect the fault level.

Rectifier substations with built-in reserve capacity for future extension or load increment may have high-speed dc breakers with higher trip ratings designed for local fault levels. A local fault has not only a high symmetrical value but an even higher transient asymmetric first cycle current. The high trip setting at the track feeder will not, however, see a low level fault which may be arcing at a point remote from the substation.

The higher capacity dc feeder breakers presently in use may well permit low level faults to persist indefinitely. With substations rated for NEMA extra heavy traction duty cycle (150 percent of normal rating for 2 hours, peaks of 300 percent for 60 sec, and 450 percent for 15 sec), the problem of distinguishing between the normal traction load current and a remote or low level fault current of a similar magnitude is not easy to resolve.

SCOPE OF STUDY

The scope of the study consisted of the following tasks:

Task 1—Perform an in-depth worldwide survey of transit systems, equipment manufacturers/suppliers, professional associations, and industry organizations to learn of their experience or knowledge of the LCFD problem.

Task 2—Identify critical system characteristics involved in low-current fault detection based on the survey information, published reports, and general knowledge of transit electrical systems.

Task 3—Using the parameters developed in Task 2, determine the extent to which the existing methods and available equipment meet the objectives.

Task 4—Incorporate research results, detailed evaluation of the performance, and cost analysis of available methods and equipment, into a final report.

The scope of study also included the requirement of seeking a solution that can easily be adopted by U.S. transit systems.

RESEARCH APPROACH

Because the survey was considered basic to the success of the project, the design of a survey instrument was very important. Test questionnaires were sent to representative transit systems and manufacturers and suppliers, while telephone contacts were made to other industries, industry and professional associations and organizations.

After reviewing the comments on the test surveys, questionnaires and letters were finalized for the formal survey.

For transit systems, the formal survey was organized into two parts. Part I asked for a brief system and low current fault (LCF) problem description to determine if the respondee had any significant LCF problems. Part II was the follow-up questionnaire requiring detailed data if the response to Part I had identified situations and occurrences of interest. A sample of both transit system questionnaires, the cover letters, and the problem statement are included in Appendix A, and Appendix G includes the transit systems contacted.

The survey of U.S. and foreign transit systems, using Part I of the Transit System Questionnaire, was conducted under the auspices of the International Union of Public Transport (UITP). UITP circulated the questionnaires in French, German, Spanish, and English languages to UITP members. The survey of non-UITP member systems was conducted directly by the Project research team and only in English, using Questionnaire Part I.

Transit System Questionnaire Part II was conducted directly by the research team, in English, for selected U.S. and worldwide systems which reported significant LCF problems.

For manufacturers and suppliers a simplified questionnaire and a letter (in English only) were used. Again, the survey was conducted directly by the research team. The form letter and a questionnaire are included in Appendix A, and Appendix G includes the manufacturers and suppliers contacted. The list of manufacturers and suppliers was excerpted from Janes World Railways, Thomas Register, and manufacturers' catalogs.

For professional organizations, utilities, and mining organizations, letters of inquiry were prepared as included in Appendix A for the Organizations listed in Appendix G.

In all categories of organizations, the project staff used all avenues, personal professional contacts, and exhaustive efforts to obtain as much detail as possible.

"Summary of Response" forms were designed for transit systems as well as for manufacturers and suppliers to facilitate the analysis and evaluation of LCFD. The analysis for the utilities, mines, and professional organizations was straightforward, based on the responses that were provided in most cases. Technical data and relevant information are included in the respective appendixes of this report.

The analysis and evaluation of LCFD devices used in transit systems and devices offered by manufacturers and suppliers were separated into two major categories: (1) devices/methods used in traction power and distribution systems; and (2) devices/methods used on-board cars.

Chapter Two presents summary data on the findings of these several surveys and evaluates the effectiveness of the survey. Chapter Three discusses and interprets these findings with respect to LCFD equipment and methods for transit systems and approaches being used in the utility and mining industries. Related issues such as safety and damage are reviewed to the extent possible with available response data and other information.

Chapter Four presents a review of the findings that provide the basis for the discussion on the resulting project conclusions and recommendations.

Additional details of the research effort, such as the survey questionnaire and format letters, summary of survey responses, technical data concerning the devices being used, and the organizations contacted, are given in Appendixes A through G. References and bibliography are included in Appendix H.

CHAPTER TWO

FINDINGS

GENERAL

This chapter reports the findings and some of the direct inferences from the several surveys carried out in the course of the study. The survey methodology for transit systems, manufacturers and suppliers, professional organizations, and other industries is briefly explained in Chapter One of this report.

The mailing list for the transit systems included 34 countries (Argentina, Austria, Australia, Belgium, Brazil, Canada, Czechoslovakia, Finland, France, W. Germany, E. Germany, Great Britain, Greece, Hong Kong, Hungary, Italy, Japan, Mexico, Norway, The Netherlands, Portugal, New Zealand, Poland, Rumania, Chile, Sweden, Spain, Switzerland, Tunis, Turkey, U.S.A., U.S.S.R., Yugoslavia, and Venezuela), with responses being received from all but 9 countries (Argentina, Austria, Czechoslovakia, E. Germany, The Netherlands, Poland, Yugoslavia, Rumania, Venezuela). The manufacturers and suppliers of 19 countries were contacted, 10 of which responded. Professional associations in Argentina, Australia, Belgium, Canada, England, France, Germany, Japan, United States, and Zaire were also contacted; no responses were received from Argentina, England, and Zaire. The mailings for other industries were limited to the United States and France.

Table 1 gives the overall percentage response rate for the test surveys, and Tables 2 and 3 present the response statistics for the formal surveys of transit systems, manufacturers and suppliers, professional associations, and other industries.

According to the UITP, the response rate for Part I of the questionnaire for transit systems is considered quite good. Some possible explanations for the lower response rate for Part II include:

- Shorter time period (as compared to time allowed for Part I).
- Lack of detailed records needed by transit systems for response.
- Staff workload required.
- Some systems may regard information on faults and consequential damage as proprietary.
- Possible difficulty of responding in English. (In this connection, note that of the 25 countries receiving Part II, 6 countries are English-speaking and of the remainder, 10 countries received the English version of Part I and responded successfully—Greece, Hungary, Italy, Norway, Portugal, Sweden, Finland, Turkey, Tunis, and the U.S.S.R.)

Nevertheless, the questionnaires for transit systems were effective and accomplished the objectives. The respondees correctly identified the problems and addressed the questions appropriately. The details of reported LCFD experience are typically scant; it appears that most systems do not keep a systematic history of short circuit occurrences. The information

Table 1. Overall response rate for test surveys.

	Transit Systems	Manufacturers/ Suppliers	Professional Associations	Other Industries
Total Percentage Responding	67	60	83	83

SOURCE: Survey Information AUTHOR: N. S. Sagar

Table 2. Statistics of formal survey of transit systems.

	Surveyed By	Questionnaire Part I	Questionnaire Part II
Total Percentage	UITP	65	N/A
Responding	Project	37	36
Percentage of Total Responding in:			
• English	UITP & Project	56	89
• French		24	9
• German		16	-
• Spanish		2	-
• Russian		2	4

SOURCE: Survey Information AUTHOR: N. S. Sagar

Table 3. Statistics of formal survey of manufacturers and suppliers, professional associations, and other industries.

			Other Industries	
	Manufacturers/ Suppliers	Professional Associations	Utilities	Mining Concerns
Total Percentage Responding	48 (40-Foreign Firms)	63	35	94
Percentage of Total by Type of Response:				
• Negative Response	50	53	-	27
• Positive Response	23	14	20	20
• Referrals	27	33	-	53
• Interested but no activity reported	N/A	N/A	80	N/A

SOURCE: Survey Information AUTHOR: N. S. Sagar may exist in file, but it is apparently not very accessible. In cases where major delays or serious fires occurred, the main circumstances surrounding the episode are usually available.

From the manufacturers' and suppliers' survey, the majority of responses received were from companies outside the United States or from their U.S. offices. Though there were some negative responses, the survey did indicate that a wide variety of LCFD devices are available from Swiss, Swedish, German, Japanese, British, French, Canadian, and U.S. manufacturers for traction power systems. Only four firms (one Swiss, one Canadian, one French, and one small U.S. firm) reported some activity in developing components for on-board car protection in association with control circuits which would help isolate and provide indication of the faulted car in the train. Most of the other devices reported are for application in traction power substations and gap-breaker stations along the right-of-way. In two cases it was reported that a detection device used in a traction power substation also detects and protects against on-board faults. The transit system that tested this device concurred, however, that they have continued to rely on their on-board devices for back-up protection.

Among the mailings to the professional associations of the United States and worldwide, typically negative responses were provided reporting no activities on the subject. Two provided referrals to the transit systems of that country and only one indicated some liaison for utilities. This was a working group on high impedance faults as part of the IEEE, T&D Committee.

In the category of surveys of other industries, utilities and mining concerns were contacted. The majority of the utilities responded negatively, though expressing interest in seeking the solution on their own for high impedance fault problems. Two utilities in the Northeast provided interesting information, while Pennsylvania Power and Light Co. (PP&LCo.), in association with Westinghouse Electric Corp., reported performing extensive work in LCFD devices. The PP&LCo. staff are also active in the High Impedance Faults Working Group of the IEEE, Transmission & Distribution (T&D) Committee.

The U.S. Department of Labor, Office of Mine Health and Safety, and the Bureau of Mines are very concerned about the low-current short-circuit problems, and all those who were contacted responded with information and referrals. Telephone contacts to most of the referrals provided the project team very helpful data on the approach of the mines to LCFD.

REPORTED FAULT EXPERIENCE

The majority of the systems responding have experienced low-current faults and 40 of the 60 transit systems reported some experience with LCFD. Summary statistics are provided in Table 4. Many of these systems reported detecting such faults successfully, and a number report they do not. Furthermore, Table 4 indicates that more U.S. systems report difficulties with detection of LCF's than the systems outside the United States. This finding is analyzed further in Tables 5 and 6.

The U.S. and other countries' experience with LCF's in traction power (TP) systems by category of equipment is presented in Table 5. It is noted that the U.S. systems responding to the survey have not installed the more recent, state-of-the-art devices, but rely mainly on the earlier types of relays.

For the earlier LCFD devices, the experience of U.S. systems is quite comparable with that of the systems outside the United States. Six out of 9 U.S. systems reported problems with LCFD in the TP area, while 9 systems out of 15 systems outside the United States reported having problems in these same categories. Apparently systems in other countries have had more satisfactory experience with LCFD than those in the United States, particularly for detecting LCF's in traction power systems.

For on-board faults, 3 systems of 9 U.S. systems reported LCFD problems; 11 of 42 systems in other countries reported these difficulties. No particular pattern is apparent, except that all of the U.S. systems, and 7 of the 11 systems in other countries, that reported difficulty with on-board LCFD either rely on their traction power LCF devices, have no devices for LCFD, or did not identify the type of equipment used. The information for on-board fault detection is presented in Table 6.

The questionnaires were reviewed for generalizations about fault experience. These are summarized in the following.

Table 4. Number of transit systems reporting LCFD problems.

	Reported Occurrence of LCF	Experienced Difficulties With LCFD	Reported No LCF Occurrence or Data Incomplete	Reported Occurrence of LCF But Not Whether Detected Successfully
Traction Power Faults				
U.S. Systems	8	5	1	1
Outside U.S.	29	10	10	5
On-Board Faults				
U.S. System	7	3	1	1
Outside U.S.	28	9	13	-

SOURCE: Survey Information AUTHORS: N. S. Sagar, H. S. Campbell

Table 5. Reports of traction power system LCFD problems by equipment/device categories.

Equipment Category	United States Systems Reporting LCFD Problems	Total No. of Systems Responding	Outside United States Systems Reporting LCFD Problems	Total No. Total No. of Systems Responding
BBC-Sécheron DDL-ACA-11 PCC-67 CERME Siemens 3UB	-	-	1	17
Rate-of-Rise Relays	4	6	1	2
Miscellaneous Devices*	1	2	5	9
No Devices Used	1	1	1	2
Data Incomplete			2	2

*Includes radar, ground resistance detector, UCP, diode in return circuit, etc.

NOTES: Transit properties responding separately for light rail, metro and commuter rail appear once for each category of equipment devices reported being used.

SOURCE: Survey Information AUTHORS: N. S. Sagar, H. S. Campbell

Frequency of Occurrence

Information on the frequency of occurrence of LCF was sparse in the survey. The analysis was primarily dependent on Questionnaire Part II returns, and as such on the 17 systems who answered the second part of the questionnaire. However, detailed information concerning this point apparently was not available.

Two reasons for this can be suggested. First, records on short circuits generally appear to be lacking or not complete. Second, it is difficult to distinguish unambiguously between LCF's and regular short circuits, because the LCFD equipment may operate on a normal short condition.

With respect to overall short circuit frequency, some respondents gave qualitative replies (such as "rarely"). Some could give no estimate, and others provided quantitative estimates and data.

Forty-six systems furnished quantitative estimates or data on their overall short circuit experience, although the systems involved varied widely in size and activity. The data for LCF occurrences were provided by only 6 systems.

It seems likely that LCF rates are understated for several of these systems, since they seem to be reporting on particular recent problems identifiable as LCF problems. The statistics for frequency of fault occurrences are presented in Table 7.

Location of Reported Faults

Data on fault location and the remaining items in this section are taken from Questionnaire Part II. As noted earlier, responses to Part II were limited, with only 17 responses having been received.

Faults were reported on both the traction power system and on-board transit cars. The location of the train was often omitted, but examples of on-board faults in tunnels, at grade, and in stations were obtained. Traction power system short circuits occurred at the substation, at the feeding point, and at various distances from the substation. The data are not sufficient to allow any generalizations about location; however, most of the LCF's reported occurred while the train was in operation, although some were reported as happening while the train was stopped at grade or in a tunnel waiting for the automatic signal to clear. One system noted that trains starting or "crowding" on opposite tracks was a matter of concern.

Faults On-Board Cars

Functional locations of on-board faults included:

- Traction motor (flashover, arcing to car body, insulation faults, ground faults, accumulation of metal dust, flashover to control box).
- Motor-alternator (M-A) set (flashover).
- Fan motor (flashover).
- Car body (arcing).
- Thyristor unit (accidental firing).
- Auxiliary systems (power fault).
- Chopper control (semiconductor overheats).
- Propulsion wiring (ground).
- Silicon control rectifier (shorted).
- Rubber tires' reinforcing wires, at failure, contacting a contact rail (for the systems with rubber tires).

Faults in Traction Power Systems

Functional locations of traction power distribution system faults included:

- Trolley wire (broken/downed and contacting car and running rail).
- Contact rail (shorted by base slab reinforcing bars).
- Track side ancillary system (arcing fault between contact rail and tunnel liners, arcing to ground via subway structure involving contact rail and running rails).
- Car frame (grounded through running rails which are part of a negative return system).
- DC positive cable (arcing caused melting of copper cable w/insulation resulting short circuit in conduit).
- Arcing across contact rail support insulator.

Factors Involving Signal and Communication Systems

There were no reports of any specific effect of low-current faults on the signal and communication systems.

Safety and Hazard Issues

The questionnaire revealed little direct evidence of hazard to passengers or transit employees. Eleven of the 17 systems re-

Table 6. Reports of major on-board LCFD problems by equipment/device categories.

	USA*1.		Outside U.S.*2.	
Equipment Category	No. Systems Reporting LCF Problems	Total No. of Systems Responding	No. Systems Reporting LCFD Problems	Total No. of Systems Responding
Misc. Devices	-	1	-	5
di/dt and Δi Devices	-	1	-	5
Traction Motor Protection Only	-	-	1	1
High Speed Circuit Breaker	-	1	1	4
Differential Devices	-	-	1	9
Overcurrent and Overload Relays	-	2	1	3
Reliance on Traction Power System Equipment	1	1	-	6
No Device	1	2		-
No Equipment Data	1	1	7	9

(1)Four systems provided equipment data but failed to report LCFD experience or had no fault experience. One system reported on two types of equipment and hence counted twice.

(2)Twelve systems provided equipment data but failed to report LCFD experience. Four systems reported on two types of equipment and are counted twice.

SOURCE: Survey Information AUTHORS: N. S. Sagar, H. S. Campbell

sponding to Part II of the questionnaire checked one or more of the following conditions: fire (6), toxic fumes (1), smoke (5), or delays (5). Three described damage to equipment. None reported casualties or unsafe conditions.

These topics are discussed further and placed in context in Chapter Three.

IDENTIFICATION OF FAULT CHARACTERISTICS

Low-current faults almost always result in a ground fault. The fault impedance contains both resistance and inductance, and the circuit current is generally expressed in a simple exponential form, with a time constant equal to L/R. The equivalent resistance, R, of the circuit can be calculated using the appropriate physical data of the running rails, parallel power cables, and negative returns. The determination of equivalent circuit inductance is much more difficult and is generally categorized into high inductance and low inductance systems.

Data on fault characteristics were provided by four systems only: SEPTA from the United States; the Metros of Montréal and Toronto, Canada; and Tyne and Wear Passenger Transport Executive of England. Brown Boveri and Siemens also provided fault characteristics data in their material, extracts of which can be included in Appendix F. In most of the cases for which data are provided, the waveshapes are plotted on a graphic recorder or derived from an oscilloscope. They included normal, starting, and fault currents against time as well as differential currents (ΔI or di/dt) against time. The data provided by the Montréal and Toronto systems include several fault occurrences.

Table 7. Monthly rate of fault occurrences.

	All Types of Short Circuits		Low Current Faults Only	
Location of Fault	Range	Median	Range	Median
Traction Power System	0-41	0.40	0.05-87	0.10
On-Board	0.06-83	1.65	0.05-40	0.60

NOTES:

1. Table presents the average monthly occurrence of reported faults for the period 7/82 to 12/83. Fault occurrence data was also reported for the sixty month period from 7/76 to 7/82; median rates for the earlier period are quite close to those shown in this table.
2. Statistics are based on 34 systems reporting occurrence rates for all types of short circuits and 5 systems reporting LCF occurrence rates. The entry for "Range" is the lowest and highest rate in each category for the systems reporting. The median value is the central rate reported: one-half the systems report a lower rate and one-half higher. It is used instead of the average because of the presence of atypically high reported rates that would tend to make the average unrepresentative.

SOURCE: Survey Information AUTHOR: H. S. Campbell

The electrical characteristic of a fault is determined not only by the type of fault occurring (arcing to car body, sagging and arcing trolley wire and foreign body grounding the contact rail, etc.), but also by the resistances and time constant of the network involved in the fault. Hence, parameteric values and LCF characteristics can vary considerably between different systems and for the various types of faults involved.

For mining concerns, the fault characteristics found were similar to those encountered in transit systems. The fault characteristics provided by the utilities included copies derived from oscilloscope graphs involving volts vs. milliseconds, frequency vs. magnitude of spectral linear component, arcing noise predominance near phase voltage maximum traces with average magnitude of arcing and nonarcing data. The algorithm used for calculation of energy over each 60-Hz cycle for an arcing fault vs. time was also included. Of course, utility systems are three-phase alternating current systems, and require more in-depth analysis involving single phase to ground and two phase or three phase to ground faults as well as complex impedance network for analysis.

EQUIPMENT IN USE BY TRANSIT SYSTEMS

Although the descriptive information on the LCFD equipment now in use was not always detailed or explicit in the responses, it was possible to identify a variety of equipment types. They are described in the following.

Traction Power System Equipment

A variety of equipment was reported in use in the United States and worldwide. These are summarized in Table 8.

On the basis of the details of the responses summarized in Appendix B, it seems that the more recently designed and complex systems are more successful than earlier systems at detecting low-current faults. A comparison of reported success at fault detection for the various categories of equipment is provided in Table 5.

One-half the systems using earlier or unidentifiable technologies reported LCFD problems both in this country and abroad. None of the systems using more recent and advanced equipment reported LCFD difficulties. Of course, these observations must be used with care. Among the reasons for caution are:

1. The newer equipment will not have been in service as long as the older equipment types and have therefore had less exposure.
2. There may be engineering considerations, particularly relating to traction power system design, condition of the transit system and its operations or fault characteristics that cause some systems to be more prone to low-current faults than others. These considerations will be addressed in Chapter Three.

Table 8. LCFD devices reported in use in traction power systems.

Device	Devices Used In United States	Devices Used Outside United States	Remarks
BBC-Sécheron DDL-ACA-11	-	9	
BBC-Sécheron PCC 67a	-	2	
CERME DCC 78	-	2	
Siemens 3UB	-	6	
Modern di/dt Devices not Specifically Identified	-	8	Based on other information provided, these appear to be BBC, Siemens, CERME di/dt devices.
GEC - Rate-of-Rise	-	2	
ITE - Rate-of-Rise	8	3	
Misc. Equipment/Devices	2	11	
None	1	-	

SOURCE: Survey Information AUTHORS: N. S. Sagar, H. S. Campbell

On-Board Car Detection Equipment

On-board detection equipment is typically supplied by the car manufacturer and delivered with the car. However, some transit systems outside the United States have reported including components and devices in the car control circuits and have taken extra precautions to monitor the values of currents at input and output of traction motors, motor-alternator sets, chopper, and the car itself. Appendix B includes a summary of responses relating to devices used on-board cars. In the United States, systems like PATH have also reported providing a prototype on-board ground fault device using a dynamic brake traction motor protection device and heater fault detection systems. Systems from Canada and Chile also indicated that their traction power system LCFD device protects on-board faults as well.

Although the data are not completely satisfactory, a variety of devices are reported in use in the United States and worldwide. LCFD devices reported in use on-board cars are presented in Table 9, while a comparison is made of the reported success of fault detection by equipment category in Table 6.

In a follow-up conversation, one transit system official offered his general observation that cars procured by some U.S. transit systems contain little combustible material and extensive steel contents to aid in preventing fires. Thus, in case of a low-current fault, the steel at proximity of the arc will melt and vaporize until the arc is long enough that it will be extinguished by itself. Usually such an incident will not result in a fire, but it will generate much smoke. Although it may appear that reducing combustible material in subway cars is highly desirable, the practice of letting an arc clear by itself (with smoke) is to say the least, but not the best solution to cope with LCF.

METHODS AND EQUIPMENT OFFERED BY MANUFACTURERS AND SUPPLIERS

The major equipment manufacturers and suppliers serving rail/transit industries with electrical equipment and devices were contacted concerning their product lines. More responses would have been helpful, but it is believed that the positive responses received did provide enough information for the available LCFD devices. The detailed data for each device, as provided, are included in Appendix C; however, Table 10 summarizes the LCFD devices offered by manufacturers/suppliers.

DEVICES USED BY OTHER INDUSTRIES

The low-current or high impedance fault is a problem by no means restricted to transit systems, since virtually every kind of machinery and electrical distribution system can experience a low-current fault. The problem has special significance to transit (and other transportation systems) because the sudden variations in electric load on these systems are diverse and similar in nature to fault currents. Nevertheless, the problem cannot be considered unique to electrified transit systems.

Inquiries about the experience of other industries were largely concentrated on electrical utilities, where high impedance faults can occur on their distribution system network. Texas A&M University has performed studies (*28, 29, 30*) on LCF's for utilities as well as mining concerns, which confirms the similarity of mining systems with the transit network.

The utilities' approaches can be summarized (*22*) in the following work program carried out by Pennsylvania Power & Light Co. (PP&L), in association with Westinghouse Electric Corp. and the Electric Power Research Institute (EPRI).

- A survey (using questionnaire) of other utilities experiencing LCF problem.
- LCF testing and development of Fault Analysis Program.
- Research studies for solutions offering protective devices that were sensitive, discriminative, reliable, secure, economic, rugged, relatively simple, easy to apply, and were quickly installed requiring low maintenance.

Some of the solutions considered were:

- Mechanical tension sensors.
- Fault enhancers.
- Reflectometry.
- Fiber optics.
- DC injection.
- Electric transients.
- Radio interference noise.

Some of the relay schemes selected were:

- Ratio ground relay.
- Undervoltage relay.
- Zero and negative sequence overvoltage relays.
- Zero and negative sequence overcurrent relays.

Fault conditions considered were:

- Normal.
- Single, two and three phase-to-ground.
- One phase open.
- One phase open, supply bus grounded.
- One phase open, load line grounded.
- One phase open, load bus grounded.
- One phase open, supply line grounded.

Table 9. Major LCFD devices reported in use on-board cars.

	USA[*1.]	Outside United States[*2.]	Remarks
Devices of Columbia Components, Inc.	1	-	
TSUDA Fault Selective Device	-	1	
Other di/dt	-	1	
Traction Motor Protection	-	1	
High Speed Circuit Breakers	2	7	
Differential Devices	4	10	Includes devices used to modify car control circuit
Overcurrent and Overload Relays	3	8	Includes devices used to modify car control circuit
Reliance on Traction			
Power System Protection	1	7	
Other Misc. Devices	-	4	
No Device & No Data Reported	2	11	

[*1.] Four systems provided equipment data but failed to report LCFD experience or had no fault experience. One system reported on two types of equipment and hence counted twice.

[*2.] Twelve systems provided equipment data but failed to report LCFD experience. Four systems reported on two types of equipment and are counted twice.

SOURCE: Survey Information AUTHORS: N. S. Sagar, H. S. Campbell

The conclusions were:

- The ratio ground relay can be used to detect current unbalance of the distribution circuits with 80 percent success rate.
- If cost is not a primary factor, sensing of negative sequence overvoltage in the feeder and branch circuits is most efficient to detect broken/grounded distribution conductors.

EPRI sponsored projects for high impedance fault detection:

- To define statistical fault parameters.
- To develop an LCFD device based on the third-harmonic current.
- To develop an LCFD device based on variations of the noise frequency components of the voltage and current waves.
- PP&L and Westinghouse developed a prototype ratio ground relay (RGR) following a detailed analog and digital modeling.
- An RGR was applied to PP&L Co. feeders and monitored. The effectiveness of fault detection reported is 80 to 85 percent.
- Further performance testing of this relay on various PP&L Co. system loops revealed a 70 to 80 percent success rate.

Additional particulars of the utilities' approaches are included in Appendix E.

The U.S. Department of Labor, Office of Mine Safety and Health, is actively interested in the LCFD problem from the standpoint of mine safety. The Division of Electrical Safety (D.E.S.) investigates fires, motor burnouts, and other electrical

Table 10. Summary of major LCFD devices/equipment offered by manufacturers and suppliers.

Manufacturer/Supplier	Model No.	Approximate Price*	Operating Principle and/or Remarks
	Devices/Systems for Use in Traction Power & Distribution System		
ASEA Inc., U.S.A. Sweden (Mfr.)	•Pilot Wire voltage sensing scheme •Relays -RXEL -RXME -RXIL24 -RADHL	U.S.$ 3500 + add'l. cost for pilot wires, installations, taxes and freight	• Voltage level comparison type DC & AC monitoring system • Provided to MTA-N.Y., NJDOT, Con Rail, Australian & Austrian Systems
Brown Boveri Corp., Canada BBC-Sécheron Switzerland (Mfr.)	•DDL Relays E-26 E-46 EN BCA PCC-67 ACA-11	Can.$ 5000 for DDL-ACA-11 Relays Prices for other relays not provided	• Works on di/dt, Δi and fixed time set principles for tripping. • Predominantly reported being used in overseas tranist systems.
Meidensha Elect. Mfg. Co. Japan (Supplier)	•Tsuda Elect. Mfr. Co. of Japan, Mfrd. •Fault Selective Device Model FE-13 •Fdr. Current Analysis Device Model AT-2F	FE-13 $3700 (FOB Japan) AT-2F $8000 (FOB Japan)	• A long list of consumers provided, which included public, private, government railroads, utilities. • Work on Δi and di/dt principle.
Mitsubishi Electric Corp., Japan (Supplier)	Tsuda Electric Mfrd. Device FE-13	•FSR device JP¥795000 •Fault detector JP¥1195000	See above
Siemens Electric Canada Siemens-Allis, U.S.A.	3UB rate-of-rise trip assembly 3UB51 relay 3UB544 transformer	Can$ 7210 or US$ 6000 plus installation taxes & freight	• Being used in conjunction with Siemens HSCB • Works on di/dt principle
GEC Transmission & Distribution Projects - England English Electric Corp. - U.S.A.	•Rate-of-Rise Relay Model 3R-1A •Inverse time Relay ITR-1 •Pilot wire voltage sensing scheme	•$600 for either relay, plus installation, etc. •Prices for pilot wire relaying scheme not provided	• 3R-1A Reported provided to South American systems • ITR-1 Reported provided to English and South American systems • Pilot wire scheme reported provided to Hong Kong MTRC.

Table 10. Continued

Manufacturer/Supplier	Model No.	Approximate Price*	Operating Principle and/or Remarks
	Devices/Systems for Use On-Board Cars		
ASEA, Inc., U.S.A. Sweden	oOvercurrent ground relays Model RXIK-1	$221/relay	• Highly sensitive relays
	oArc monitor TVOA for traction motors	$500/unit or less	• Offered for "within the gear" installation to detect arcs in traction motors
oBrown Boveri, Canada oBBC-Sécheron, Switzerland	oHSCB Type UR-12 oHSCB Type UR-6	Price not provided	• Operates on di/dt principle depends upon time constant of the protected circuit
Columbia Components NJ, U.S.A.	oGround fault & dynamic brake traction motor protection oHeater fault detection system	oPrice not provided but verbally mentioned cost $25000 to develop prototype unit.	• Saturable reactors sense the current unbalance in traction motors. • Works on heater supply voltage fluctuations.

SOURCE: Survey Information AUTHOR: N. S. Sagar

*Price is approximate as quoted for year ending 1983.

system problems, performs physical inspection, and obtains voltage and current readings, as well as developing computer simulations. The Berkely Laboratory of D.E.S. is also concerned with equipment acceptance criteria. The emphasis at D.E.S. appears to lie more on encouraging a high level of trolley systems maintenance rather than on the LCFD devices.

The U.S. Bureau of Mines Office of Research also takes an active interest in LCFD from concern about mine safety. Bureau of Mines spokesmen believe that the majority of mine fires are due to ground faults in the mine traction power system. The Office of Research recognized that the problem is a difficult one, and instead of attempting to improve existing or state-of-the-art ground fault protection relaying with its inherent limitations, devoted their resources to developing more advanced systems. Some of the projects reportedly funded by this office are the following:

- A project in 1976 developed a device or system that made use of an audio-frequency signal imposed on the dc traction supply. A short circuit to ground would sharply reduce the impedance seen by the audio signal. This project was apparently technically feasible, but was not carried on to the point of implementation, reportedly because of the cost ($50,000 per substation) and concern about manufacturer's liability.
- Development of a discriminating circuit breaker.
- More recently, work on a system incorporating a microprocessor was initiated, but this project has been discontinued.

Other approaches used to mines railways include:

- Use of a timed overcurrent device.
- Use of 600V dc di/dt device for 300V dc system.

These projects did not proceed to the point of completion and implementation, according to the information provided. However, additional details are included in Appendix E.

RESPONSES FOR DEVICES AND METHODS RECOMMENDED BY PROFESSIONAL ASSOCIATIONS

From about 30 professional associations contacted within the United States and other countries, the research team received three positive responses, of which two were referrals to other organizations. These latter provided LCFD device information. The third responding was the IEEE, T&D Committee, which has a working group on high impedance faults that was created in 1983.

The group provided very valuable information on LCF detection in utilities, which was discussed earlier in this chapter. The pertinent details of responses from professional associations are included in Appendix D.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATIONS, AND IDENTIFICATION OF METHODS AND EQUIPMENT FOR LOW-CURRENT SHORT-CIRCUIT DETECTION

GENERAL

This study was designed to document present practices for LCFD and, if possible, provide definitive answers to a number of questions:

1. Is there widespread recognition of the LCF problem?
2. Are undetected LCF's perceived as a serious or potentially dangerous situation?
3. What components or systems give rise to on-board LCF's most frequently?
4. What causes LCF's on the traction power system most frequently?
5. What are the electrical characteristics of the LCF's?
6. What particular systems characteristics tend to be frequently associated with LCF's?
7. What LCFD devices are in use?
8. What is industry's experience with this equipment?
9. What LCFD devices are offered from suppliers to the transit industry?
10. Have industries other than the transit industry developed equipment or approaches that might be transferable?

For questions 1 to 8 the survey of transit systems throughout the world, supplemented by knowledge gained through discussions with transit officials and manufacturers representatives, in conjunction with the engineering background of the project team, provided most of the answers.

Question 9 is addressed by the survey of manufacturers and professional or industry organizations relating to rail and transit; question 10, by the survey of other industries and professional or industry organizations relating to other industries.

The data reported in these surveys are presented in Chapter Two. In this chapter the findings are amplified, interpreted, and evaluated.

REVIEW OF TRANSIT SYSTEM EXPERIENCE

Extent of Low-Current Short-Circuit Problem

That the low-current short-circuit problem is pervasive is indicated by the fact that 68 percent of the systems responding have experienced LCF's, and 38 percent of those had some difficulty detecting them. All of the U.S. systems responding had experienced LCF's. More interesting still are three related findings:

1. U.S. transit systems report more difficulty with LCFD than do the systems of foreign countries.
2. The approach to LCFD by U.S. systems uses older concepts and equipment that were never in use or were considered obsolete in other countries.
3. Those foreign systems that did report LCFD problems were generally using equipment based on the earlier principles, i.e., similar to those in use in the United States.

These observations are much clearer for traction power system LCFD equipment and experience than for LCFD equipment being used on-board cars. The majority of transit systems in the world have low-current faults, but only one-third of the systems reported detection problems in their traction power system as well as on-board cars. Over one-sixth of the transit systems reporting problems on-board cars did not report anything about the equipment installed in their cars. Excluding those transit systems that did not respond, it appears that other countries' success at LCFD is somewhat better than the United States', just as their concepts and equipment are more modern and represent the state of the art.

The project staff also investigated the question of whether there are system characteristics or operational reasons aside from the type of detection system in use that might account for success or lack of success in LCFD.

Though the survey questionnaires were designed to receive as much system operating and design information as possible, the evaluation of the survey revealed no general relationship with fault frequency or detection success. At the broad level of investigation possible with reported data, the type of LCFD device/equipment or lack thereof represents the primary cause of detection problems.

Safety and Hazards, Damage, Delays and Disruption

Part II of the questionnaire includes questions about "unsafe conditions" (presence of fire, smoke, toxic fumes) and delays. The responses to these questions varied, some reporting one or more of the "unsafe" categories and delays, some delays only, and still others left these questions unanswered. Of the eight responding to this set of questions, three reported delays only, one reported no delays or unsafe conditions, four reported occurrence of fire, and one reported serious damage to a rectifier unit. Two systems reported hazardous conditions in addition to fire. Although this is a regrettably small set of data, the results for those who reported are entirely in line with the expectations of the research team. Most short circuits, even low-current faults result in some damage and must be considered potentially hazardous.

It is generally recognized that although serious incidents due to fire have been rare, the potential exists, particularly in underground systems. Whether a short circuit gives rise to a life-threatening situation depends more or less on an accidentally determined set of circumstances: how crowded was the train, where was the train when the problem occurred, how quickly was assistance provided, how the transit facilities allowed emergency evacuation, and so on. Regardless of the cause, although emergency services are available, transit systems could experience some casualties and/or service disruption. The disruption could range from 5 to 10 min, to several months, depending on the extent of damage. The frequent nondetection of LCF resulting in either of these situations could easily earn a bad reputation for any transit system.

The significance of electrical faults as safety hazards can be obtained from reports or investigations of all transit incidents. For example, the National Transportation Safety Board (NTSB) published two recent reports of transit incidents involving fire and smoke, an evident hazard to riders, transit staff, and safety personnel (*19, 20*). These reports briefly summarize the findings of an investigation of 12 major incidents on these transit systems. All those incidents involved electrical fires. From the information presented, it appears that in one case only a dc feeder breaker in a traction power substation did operate to deenergize the system. The other cases apparently were "low current faults," i.e., the fault current was not large enough to operate the protective relays or series trips on the traction power system.

In the NTSB summary reports, the protective relaying systems did not become an issue in the investigation. A review of the NTSB's recommendations shows concern about a number of highly important questions—including transit management's ability to both recognize dangerous patterns of equipment malfunction and to institute preventive maintenance or redesign, the flammability of materials used in the cars, and, most importantly, the planning and procedures for dealing with emergencies when they occur. (It is important to note that these examples are not intended as a summary of the 46 conclusions and 48 recommendations of these two reports.) It seems evident that the ability of protective relaying equipment on the car and at the substation to sense fault conditions and deenergize the equipment involved should also receive attention in an investigation of a life-threatening fire. This leads to the inevitable conclusion that engineering and testing of low-current fault detection systems should become a major element in safety assurance programs. (The exact way in which protective relaying is integrated into the overall safety engineering plan may require study. For example, one aspect of the problem to be considered is, judging from the accounts in references (*19*) and (*20*), that it may be necessary to move a train which is burning to a location where passengers can be evacuated. This implies a high quality LCFD device that can shut down only the car actually involved, leaving the remaining cars in the train able to move under control. The desirability to move the car may be another subject of debate. An LCF on the traction system is still another matter. Safety considerations must dictate what actions to be taken when the fault is detected.)

With respect to property damage, some types of damage to cars and tunnel walls were described in the responses. It is not possible to estimate costs from this information, but the damage does not seem to have been severe. The costs associated with major fires can, of course, be very high. The National Transportation Safety Board (NTSB) (*20*) reported that between January 27, 1979 and December 22, 1980, the New York City Transit Authority experienced 66 motor control group "heavy burn ups" on the IRT Division. In their report, NTSB suggests that inadequate inspection and maintenance were the contributing causes; however, adequate LCFD equipment might have reduced damage and achieved substantial dollar savings.

METHODS AND EQUIPMENT REPORTED IN USE BY TRANSIT SYSTEMS

On the basis of the responses, the following are the methods and devices reported being used in the worlds' major transit systems.

Devices and Systems Being Used in Traction Power Systems

- Load measuring system.
- Timed and instantaneous overcurrent protection.
- Pilot wire scheme.
- James A. Biddle ground detector device.
- Lead sheath protection system.
- Devices working on change of current (Δi) principle line fault detector of BBC-Sécheron, and fault selective device and dc feeder current analysis device both of Tsuda Electric Co.).
- Devices working on rate-of-rise of current, di/dt, principle (ITE-76T of BBC-Gould-ITE, PCC-67a of BBC-Sécheron, 3UB rate-of-rise trip assembly of Siemens, DCC-78 of CERME).
- Unbalanced current protection
- Earth potential detector

  } As used by the London Transport Executive of England (LTE)
- Fixed high frequency superimposing technique (details undefined).
- Electronic protection (details undefined).
- Diode in negative return circuit—diode becomes conducting on the increased ground potential, provides instantaneous alarm and indication.

Devices and Systems Being Used On-Board Cars

- High-speed circuit breakers.
- Differential relay/ground differential relay.
- Instantaneous and time overcurrent devices (overcurrent braking relay and overcurrent field exciting relay).
- Current overload relays (current overload ground relays, motor alternator set overload relay, braking overload relay, overhead series and parallel relay, overload control relay).
- Fuses.
- Contactors with internal overload.
- Current sensors in the car control circuits.
- Charged coach detector (details undefined).
- Chopper current monitoring devices in car cabin.
- Contactor box excess heat detector (details undefined).

The project staff reviewed a wide variety of responses, some of interest are as follows:

- Though some systems report that no true LCFD device is in use and that cars are protected only by differential relays in addition to fuses, on-board LCF's, as well as LCF's in traction power systems, were detected.

- Two systems with older facilities and equipment satisfactorily detected LCF with the ITE rate-of-rise (76T) relay. A third system with newer equipment, and the fourth system with older equipment, are in doubt as to whether the ITE-76T relays detect the low-current faults.
- High-speed circuit breakers on-board cars were reported detecting LCF's satisfactorily on two systems, while one similar system reported them functioning unsatisfactorily.
- A system having a grounded return current system with considerably long contact rail sections (up to 5 km) using the 3UB type rate-of-rise trip assembly reported difficulty in detecting LCF's in the traction power system, as well as on-board cars. Another system with similar parameters, except with an ungrounded return current system, detected LCF's on the traction power system. However, neither system reported that they could detect on-board faults using a 3UB device in the traction power system.
- Pilot wire voltage sensing relaying seemed to be working satisfactorily in one older system, although the newer Hong Kong metro system reported difficulty in detecting LCF's. However, there are no reports of a pilot wire scheme detecting on-board faults. Unless a new system is being constructed, the economics of retrofitting an existing system with a pilot wire scheme are not favorable. Some transit systems report using fiber optic cables for transfer tripping functions to avoid an interference effect, which is often encountered in hard wired schemes.
- The London Transport Executive has applied unbalance current protection (UCP) and earth potential detection (EPD) schemes for low-current fault detection. They are performing satisfactorily for LCF's in traction power systems, but there are no reports of their performance for LCF's on-board cars. The UCP and EPD schemes perform well even under conditions of crowding of trains in the same section or starting in opposite directions at the same time near a substation. Here again, the LTE system, unlike U.S. transit systems, uses two running rails and two contact rails, resulting in a completely ungrounded and isolated system.
- The line fault detector, DDL-ACA-11, and the di/dt relay model PCC-67a, are devices offered by BBC-Sécheron. None of the U.S. systems reported using such devices. They are highly rated by the transit systems outside the United States, with the exception of the Tornoto Transit Commission (TTC) of Canada, which expressed otherwise. TTC conducted tests of DDL-ACA-11 relays in two phases, the first on its new Scarborough line and the second in its longest section of a mass transit line. The project staff was verbally informed that DDL-ACA-11 relays did perform satisfactorily for all cases of faults except for the detection and clearing of arcing faults. This could be a situation where the sensitivity range modification may be required for the TTC system; however, BBC-Sécheron has not completed the study of the TTC problem. The PCC-67a relay has been applied on metro systems with rubber tires. The device is reportedly shared by four negative contactors in existing substations with train operating on a 2-min headway in Montréal Metro. The PCC-67a relay can be used on partially or fully grounded and floating return current systems. The Montréal Metro is scheduling a thorough testing of the DDL-ACA-11 in the near future prior to its adoption in place of PCC-67a relays in dc positive feeders of its network.

The DDL-ACA device performs most of the functions of PCC-67a, but it is described by the manufacturer as the latest model, embodying state-of-the-art techniques. The device works on the Δi principle and is relatively inexpensive. (It is of interest to note that in a telecon with BBC-Sécheron, MAIN was informed that after the testing mentioned in the comment, the DDL-ACA device was modified to include the option of interrupted arc protection. With this change the manufacturer confirmed that both devices will have similar functions.)

Technical data of major detection systems reported appear in Appendix F. Because no information was provided for custom devices by transit systems reported using them, their technical data were excluded from Appendix F—similarly for fuses and contactors because they are used universally in many applications and their technical data can easily be made available.

With respect to on-board car protection, the majority of newer cars come equipped with high-speed circuit breakers, possibly working on the di/dt principle, differential and overcurrent devices.

Some transit systems seem to be searching for a solution by analyzing car control circuitry. Some of the devices reported being used to modify the control circuit for early detection and protection of on-board faults are:

- Current overload ground relays.
- Motor overload relay.
- Motor-alternator set overload relays.
- Braking overload relay.
- Overload series and parallel relay.
- Overload control relay.
- Overcurrent braking relay.
- Overcurrent field exciting relay.
- Overcurrent control relay.
- Car current differential relay.
- Ground current differential relay.
- Motor current differential relay.
- Chopper current differential relay (for input and output).

Some of these devices are noted as being installed in older cars as well as being furnished with new car procurement.

There are reports of one small U.S. manufacturer, the Columbia Components, Inc., who has developed a fault detection system for ground faults and dynamic brake traction motor protection as well as for heater fault detection systems. PATH and New York City Transit Authority verbally reported separately from the survey that they were pilot testing these devices, and PATH confirmed their satisfactory performance. However, information and data were insufficient to permit evaluation.

METHODS AND EQUIPMENT OFFERED BY EQUIPMENT MANUFACTURERS

Table 10 in Chapter Two highlighted the major devices and methods offered by manufacturers and suppliers throughout the world. Most of the overseas manufacturers/suppliers have U.S. offices.

There seems to be a lack of activity in the LCFD field by U.S. manufacturers, as none of them have responded to the questionnaire. It is possible that U.S. electrical equipment manufacturers do not see a sufficiently attractive market for these rather specialized detection devices and hence often debate whether or not to spend their funds in research and development.

A number of unusual systems are reported in use, e.g., a radar system, a lead sheath protection system, fixed high frequency superimposing techniques, electronic protection, and so on. No specific description of the principle of operation for these systems was provided. They appear to have been specifically designed for the system involved, possibly by the system's own staff. It is impossible to assess these devices at this time.

The manufacturers' cost comparison and reported effectiveness in application can be made of devices offered by BBC-Sécheron, Siemens, Meidensha Electric, Mitsubishi, ASEA, and General Electric Company of England (GEC). The pilot wire scheme is comparable in cost to the DDL-ACA relay and PCC relay, both of BBC-Sécheron, and the 3UB trip assembly of Siemens. It cannot be determined from survey information whether the pilot wire scheme, the Siemens 3UB device, or the GEC rate-of-rise relays cover on-board faults as well.

As far as simplicity of adjustment and operation is concerned, pilot wire voltage sensing would seem to present no difficulties and there are reports of it being used by Long Island Railroad and New York's Metropolitan Transit Authority in the United States.

BBC-Sécheron devices seem to be more complex, although reported more widely used than Siemens 3UB rate-of-rise trip assembly. The reported experience in Canada and South America reveals that "BBC-Sécheron devices are operating perfectly for almost all categories of faults." The device has been modified for the interrupted arc circuit sensitivity feature for one transit system. This feature has more importance in systems with rubber tires.

Apparently the purchase price of a PCC device is almost five times more than a DDL-ACA-11 device; however, it seems that the DDL-ACA-11 is preferred over the PCC-67. Although there are mixed reports of the effectiveness of the 3UB trip assembly device from the European systems, in general, its performance seems to be comparable to that of the DDL-ACA-11 device.

For on-board fault detecting devices, those most frequently reported being used are:

- High-speed circuit breakers (HSCB).
- Differential devices.
- Overcurrent devices.
- Overload devices.

HSCB, offered by the BBC, which operates on the di/dt principle, is thoroughly discussed in Appendix F.

Other on-board detecting devices, with the exception of the one offered by the Columbia Components, Inc., seem to have been designed and applied for individual system parameters and operating policies or philosophies.

A cost analysis could not be performed because of lack of cost information of all on-board detection equipment. However, the most commonly used on-board devices can be purchased off-the-shelf from various electrical equipment manufacturers involved in the rail/transit field.

METHODS AND EQUIPMENT REPORTED IN USE BY OTHER INDUSTRIES

Utilities and mines report low-current fault problems on their power distribution systems that are similar to the transit system LCF problems.

Electric utilities have similar power distribution systems to transit systems, in the cases of long single phase distribution feeders. The general exceptions are:

- Utilities have smoother loading cycles, unlike the train loads.
- Most of utilities' distribution is of 3-phase ac and radially connected.
- Generally the faults require a more complex analysis than in those occurring on dc transit systems.

The broken conductor situation can easily create low-current faults and safety and hazard concerns. Some details of analysis are discussed in Chapter Two and in Appendix E. The step-by-step approach to finding the LCFD solution comes very close to the approach the transit industry must follow.

Electric utilities have used system analysis, digital modeling, and prototype development, and have performed field testing to find a device which could satisfy their system reliability requirements. EPRI-sponsored work for the utility industry investigated the development of detecting devices using higher audiofrequencies, presumably similar to those which have been reported in use on transit systems in Europe without accompanying much detail.

Other devices tested monitored the current increase or rate-of-rise of current during ground faults similar to some of the detecting devices now available to transit systems.

The mining industry, on the other hand, has a very similar problem in the detection of low-current faults, as the transit system. In addition, the ramifications resulting from failure to detect are much like the hazard conditions that short circuit and any resulting fire may produce in transit tunnels.

Governmental agencies concerned with mine safety have undertaken several research projects with similar objectives. They have pursued audiofrequency and high-frequency techniques and also addressed the possibility of using discriminating circuit breakers, the details of which are included in Appendix E. However, these projects are reportedly nonconclusive or were never completed.

ANALYSIS OF INFORMATION PROVIDED BY PROFESSIONAL ASSOCIATIONS

The survey of professional associations reported very little information of interest to the transit industry about activities or studies undertaken or sponsored by them, which could be utilized for the U.S. transit systems.

The IEEE, T&D Committee, however, does have an active working group on high impedance faults. The chairman of the group and other group members provided the project with most of the information on LCFD or studies by utilities as discussed earlier. Further details are presented in Appendix E.

CHAPTER FOUR

REVIEW OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Chapters Two and Three discuss in detail the information provided by the surveys. The general and specific conclusions to be drawn from a review of the findings discussed in those chapters are summarized as follows. The discussion in the remainder of Chapter Four contains suggestions for improving LCFD operations and maintenance practices and includes, as well, recommendations for developing programs to improve LCFD in the U.S.

GENERAL CONCLUSIONS

Several general observations supported by the survey data are:

1. A variety of LCFD devices, systems and practices were reported in use by worldwide transit systems. See the subsection entitled, "Methods and Equipment Reported in Use by Transit Systems" in Chapter Three, for a detailed discussion and description.
2. From the reported system experience the equipment varies in effectiveness, more modern devices performing better than older devices.
3. U.S. systems generally use devices based on the earlier designs, and they report less success in general than do systems outside the United States that use state-of-the-art devices. Systems outside the United States that use older devices report less success with LCFD.
4. Several transit system parameters were analyzed in a search for a possible relationship with LCF characteristics and the LCFD devices used. Some of the LCF characteristics considered include:

- Grounded vs ungrounded system.
- Track sectionalization and track bonding arrangement.
- Contact rail types and feeding arrangement.
- Train headway.
- Age of the transit system.
- Frequency of LCF's and other short circuits.

The project staff used all possible avenues—personal and professional contacts and exhaustive efforts—to collect the data on the various types of LCFD devices available and being used worldwide. However, it was not possible to form useful generalizations for a relationship based on the analysis of such data. This may partly be because the LCF occurrence frequency data are limited and partly because the number of system configuration variables is large. In addition, no information was gathered on such factors as equipment design defects and on the state of maintenance. These factors probably have an important impact on fault occurrence frequency. Nevertheless, the power system data which were provided were useful in interpreting the fault information in several instances.

Some potential for ambiguity in the design objectives for LCFD devices was also noted. Detection on the traction power systems and that on-board transit vehicles are typically viewed as separate fault detection problems; ideally the traction power and on-board systems should be analyzed simultaneously. Some systems depend on traction power devices for on-board protection which may have some merit from the initial engineering and cost standpoint. On the other hand, it might be argued from the standpoint of safety and reduction of delay that an ideal fault protection system would allow faulty cars to be isolated and deenergized while permitting the unaffected cars of a train to be operated. Broad considerations relating to systems as a whole, of which this is an example, suggest the value of comprehensive design objectives, integrated design, and testing of the entire fault detection system.

SPECIFIC CONCLUSIONS

The following findings are derived from consideration of the survey data, and the analysis of that data and the detailed underlying information.

1. Alternative traction power LCFD devices can be compared with respect to effectiveness in actual operational situations, and significantly improved performance can be expected through a combination of equipment selection, system design, and testing on the system.
2. The on-board fault detection history, as reported, presents a less satisfactory picture than does traction power LCFD from the standpoint of identifying promising LCFD approaches. The LCFD systems of recent design appear to be somewhat more effective in on-board fault detection, however; but philosophies or objectives appear to vary. Some transit systems rely completely on devices installed in the traction power system and do not attempt LCFD with on-board equipment; others employ a variety of devices in combination.
3. On the basis of the analysis of responses, the following devices/systems seem more significant and promising.

- Traction power system LCFD devices that appear to perform well on a variety of transit systems outside the United States and the United Kingdom are solid state Δi and di/dt devices. The most prominent devices include the BBC-Sécheron DDL-ACA-11 and PCC-67a, and the Siemens 3UB trip assembly.
- On-board devices that appear to work well are described as differential protection devices—relay devices that compare the difference in current flowing between two or more points

in the motor and controller circuits. Differential devices are often reported being used in conjunction with fuses, overload relays, overcurrent devices, and lately with the on-board HSCB on di/dt principle.

4. It is difficult to assess the benefit of improved LCFD equipment/methods quantitatively. However, the survey results and other documents present accounts of damage incidence and possible hazard to human life. This should provide a strong motivation for further development and upgrading of LCFD systems in the United States.

5. System delays and disruption were rarely reported in the survey responses though it seems evident from other sources that undetected LCF can be a source of very significant delays.

SUGGESTIONS REGARDING OPERATIONS AND MAINTENANCE

From the survey results and follow-up conversations, it appears that the frequency of faults and the severity of the resulting unsafe conditions can be markedly affected by the state of maintenance and house-keeping operations on the transit systems. The following excerpts of steps taken by various transit operators are suggested for consideration in improving operations and maintenance practices regarding LCFD:

- Maintenance programs to keep the stations and tunnels as clean as possible (for newer subways, cleaning after each rush hour has proved to be very effective).
- Control of metal dust by periodically removing it.
- Maintenance programs to check cars (especially underneath) for: condition of current collector shoes, connections and miscellaneous wiring; and periodic cleaning of all welding, which has been reported to cause flashovers in the commutator motor as well as in the motor-alternator set.
- Monitoring of current per car, current per motor, current differential, and the difference of chopper input and output current in the car-operator cabin during operation for any indication of change from normal values.
- The NTSB recommends increased emphasis on reporting of maintenance incidents and, presumably, operation of breakers from short circuits. This should be complied with increased management attention to identifying and correcting problem equipment or operational practice.

Requirements such as the foregoing may reduce the number and severity of LCF's and justify relatively simple and less costly LCFD approaches.

PROGRAM RECOMMENDATIONS

It is a fact that the Agency can make its own decisions within its constraints. However, it is recommended and is critical that efforts to improve LCFD in the United States by installing one of the newer devices or systems should be preceded by a thorough analysis of system parameters and operating characteristics followed by a systematic testing program. The process and procedures of the system analysis and testing program comprise an important and demanding assignment.

Initiatives available include the following.

Development of standards and guidelines to assist U.S. transit systems in designing and carrying out a system analysis and test program for LCFD. The development of guidelines for assessing the present system, performing a rigorous, individualized cost-benefit analysis, and determining suitably broad design objectives should be included. The experience of transit systems such as metros of Toronto, Montréal, Paris, and Santiago, where extensive test programs have been conducted, would be relevant and valuable. A paramount concern in establishing system design objectives would be safety enhancement.

Fund a system analysis and test program in cooperation with a U.S. transit system. Such a program would be more comprehensive than might be possible for a self-sponsored test by a transit property. More alternatives might be considered, and detailed test reports would be made available to the industry. The criteria for selecting a system for a testing program might include:

1. The availability of a mix of metro and light rail service.
2. A range of ages in the transit system and their facilities.
3. Types of traction power and distribution system equipment and rolling stock.
4. A dedicated interest on the part of transit system owners/operators towards improving LCFD means.
5. Requirements for identifying fail-prone on-board components and the procedure for their monitoring.

The following should be considered in developing a testing program for a selected device:

1. Continuous automatic monitoring and analysis of each current increase, rate-of-rise of current, time values for their persistance and time delay settings, etc., during the transit system operation.
2. Continuous comparison of parameters such as mentioned in item 1, possibly using computer simulation, with memorized signature values having allowable limits that were set based on the operating characteristics, philosophy, and operating policies of a transit system.
3. Evaluation for a fail-safe, self-locking and the means of indication for an LCFD device.
4. Evaluation of the train performance model for the possible inclusion of an LCF input to provide insight into the expected frequency and location of LCF's arising from operations or malfunctions.

The motivation for the test program, or with the design and test guideline development, is damage reduction, delay reduction, and most importantly, safety enhancement.

ALTERNATIVE SYSTEMS FOR LCFD

In developing a program for LCFD improvement, whether undertaken privately, as a joint governmental transit operator project, or as a wholly governmental study, a thorough testing program should be planned after carefully reviewing a transit system specification and operating characteristics within their allowable constraints. Several alternative systems should be studied and assessed. These alternatives for application in the traction power system are described below in order of decreasing complexity. The options for on-board LCFD devices should be assessed simultaneously.

- LCFD in Traction Power System Application

Alternative 1: Solid State Δi and di/dt Devices. Solid state devices on the Δi and di/dt principle are offered by several manufacturers in Europe. Most of them maintain and serve the U.S. market from their local U.S. offices. These devices are available in varying complexity; however, careful analysis and planning will be required for a transit system considering an application. A proper di/dt or Δi device should be selected following a thorough testing involving bolted, arcing, and high resistance faults in the worst possible situation. These devices, as recommended by the manufacturers, can be used for any and all combinations of transit systems of varying characteristics and parameters. The major di/dt and Δi devices successfully being used outside the United States are discussed in detail in Appendix F.

Alternative 2: Pilot Wire Scheme. Installation of a pilot wire system may be quite economical when a new route is under construction and pilot wires can be installed in the right-of-way without great expense. The pilot wire system can be used for either voltage and current sensing. It is simple in application and maintenance. See Appendix F for details. There have been some reports of misdetection with this system which may have been related to operating practices.

Alternative 3: Unbalanced Current Protection in Conjunction With the Earth Fault Potential Detection. For the systems with no present LCF protection, this could be the most economical approach if its present return current system is ungrounded and isolated. Unbalanced current protection, in conjunction with earth fault potential detection, is reported to function well for protection against traction power system low current faults. The details of the system are discussed in Appendix F.

- LCFD for On-Board Application

The following are possible devices/methods that can be considered for on-board car detection schemes.

- Modification of car control circuitry to use differential devices, overload relays, and overcurrent devices.
- Monitoring various current differentials and training operators to recognize and respond to normal and emergency indications in the operator's cabin.
- Use of microprocessors to recognize departure from the normal signature.
- Application of specialized devices such as the Ground Fault and Dynamic traction motor protection and Heater Fault Detection system which was reported being pilot tested by the PATH system.

The foregoing suggestions for equipment testing incorporate existing devices and approaches. This was the basic objective of this research project. The survey strongly suggests that an LCFD problem cannot necessarily be solved by procuring and installing a "black box": it is highly advisable to analyze the fault problem and plan a comprehensive implementation program including testing and system changes as necessary. Further, it is considered imperative to approach the problem from broad design objectives that will look at both traction power and on-board detection to assure that the overall improvements in fault detection capabilities result in optimum benefits in enhanced safety and property loss reduction.

APPENDIX A

SURVEY QUESTIONNAIRES AND FORMAT LETTERS

MAIN
1893

CHAS. T. MAIN, INC., Engineers
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262-3200

Date

SUBJECT: Detection of Low-Current Short Circuits

Name and Address of
Transit Authority

Attention: Engineering Department

Dear Sir:

Chas. T. Main, Inc. (MAIN) is conducting a research study in the area of electrical fault detection systems presently in use of electrified transit and rail systems. A more complete but nevertheless brief statement of low-current short circuit problems is attached herewith for your further information.

This work is being performed for the National Academy of Sciences (Subcontract No. TR43-1) under the National Cooperative Transit Research Program.

Our objective in this project is to assemble relevant information on how the transit operators are dealing with such low level faults on their system. We will be conducting a detailed survey of this problem worldwide through the International Union of Public Transport using a survey instrument similar to the one enclosed here as the test survey questionnaire.

We are asking several transit systems to assist us by completing this test (or draft) questionnaire and noting its shortcomings or any difficulties it presents. These comments will be reflected in the final version, which will be sent to all transit properties.

Please return the completed questionnaire, with your comments, in the envelope provided. If you think you or your division are not appropriate for this inquiry, please forward it to the respective personnel or division in your organization.

NEW YORK, NEW YORK • BOSTON, MASSACHUSETTS • CHARLOTTE, NORTH CAROLINA • PORTLAND, OREGON

Your assistance will be very important to our success of this project. Your cooperation will be most highly appreciated.

Very truly yours,

CHAS. T. MAIN, INC., Engineers

Navin S. Sagar,
Principal Investigator

NSS/nr
Attachment

QUESTIONNAIRE ON THE LOW CURRENT SHORT CIRCUIT PROBLEM

PART I

1. System Identifiers

Agency or Authority Name____

City____________________ Country________________________

Note: Do not answer the boxed items; information will be obtained from published sources.

2. System Description

a. System Type ☐ Mass Transit (Circle if Subway, Elevated)
☐ Commuter ☐ Light Rail ☐ Other (Specify)

b. Catenary/Contact Rail - Range of Operating Voltage ________ Volts Max.
☐ AC ☐ DC ________ Volts Min.

c. Percentage Right-of-Way - In Tunnel ________
- At Grade or Open Cut ________
- Elevated ________

(Circle one.)

d. Length of Electrified Right-of-Way - Single Track ________ km or Mile
- Double Track ________ km or Mile
- Four Tracks ________ km or Mile

3. Rolling Stock (Cars) in Operation on Your System

For each type, model and series, please provide the following:

Car Type 1

a. Total No. of Cars of This Type ______

b. Car Data:
Manufacturer____________________
Type____________________
Model____________________
Year of Delivery____________________
Type of Control System____________________
Cam Controlled
Chopper Controlled
Other (Specify)

c. Traction Motor Data:
Manufacturer____________________
Type____________________
No. of Motors per Car____________________
Full Load per Car
Starting Current ________ Amps
Running Current ________ Amps
Cars per Train ________

d. Please attach sheets for car types 2, 3,.......etc.

4. Onboard Fault Experience

a. Have you experienced short circuits onboard your trains? ☐ Yes ☐ No
If Yes, how frequently?
*No. of incidents since July 1, 1982 ____________
*No. of incidents between July 1, 1976 and July 1, 1982 ____________

b. In general, were short circuits detected successfully? ☐ Yes ☐ No

c. Have you encountered low level or arcing type faults? ☐ Yes ☐ No

d. In general, were low level or arcing type faults detected successfully?
☐ Yes ☐ No

e. Type of on-board low current short-circuit detecting device on
Car Type 1____________________
Car Type 2____________________
Car Type 3____________________ (Attach sheet, if necessary.)
Car Type 4____________________

5. Traction Power Supply System Descriptors

a. Power Supply to Trains by ☐ Catenary ☐ Contact Rail

b. With catenary system, overhead support structures are ☐ Grounded
☐ Connected to Running Rail

c. Type of Current Return System ☐ Grounded ☐ Ungrounded ☐ Other (Specify)

d. Length of Individual Electrified Section ________ km or Mile (Circle one.)

e. Traction Power Substations
Capacity ________ MW/MVA
Age of Equipment ________ Yrs.
Rating of Contact Rail/Catenary Feeder Breaker ______ Amps
No. of Substations per Electrified Section ________
Traction Power Feeding Arrangement ☐ Single End Fed
☐ Double End Fed ☐ Center Fed

f. Does your system use: 1. Contact Rail Disconnect Switches ☐ Yes ☐ No
2. Gap Breaker Stations ☐ Yes ☐ No

g. No. of Feeder Breakers in a Typical Substation_____ Gap Breaker Station______

h. Minutes of Headway During Rush Hours________ During Non-Rush Hours________

6. Traction Power System Fault Experience

a. Have you experienced traction power system short circuits ☐ Yes ☐ No

If Yes, how frequently?
*No. of incidents since July 1, 1982 ____________
*No. of incidents between July 1, 1976 and July 1, 1982 ____________

b. In general, were short circuits detected successfully? ☐ Yes ☐ No

c. Have you encountered low level or arcing type faults? ☐ Yes ☐ No

d. In general, were low level or arcing type faults detected successfully?
☐ Yes ☐ No

e. Type of low current short-circuit detecting devices in use in your traction power system. ____
____
____

7. We would appreciate learning the particulars of any engineering analysis or studies of the low current short-circuit problem carried out by you or your organization. Please attach reference or reports, if available.

8. Name, title and telephone no. of individual completing this questionnaire.

____
____

Thank you. Please return this questionnaire in the envelope provided.

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*Please use estimated data only if records are not available but indicate by "Est."

QUESTIONNAIRE ON THE LOW CURRENT SHORT CIRCUIT PROBLEM

PART II

Agency or Authority Name: ______________________
City ______________ Country ______________

1. Details of Low Current Short-Circuit Fault Detection Equipment Onboard Trains or Cars

(Refer to your response to our earlier questionnaire, copy attached, for car type designation)

For each type of car you operate, please describe the low current short-circuit detection equipment carried onboard.

Car Type 1
Fault Detection Equipment
Manufacturer ______________ Type ______________ Model ______________
Principle of Operation ______________________
____
Evaluation of suitability, consistency of performance, etc. ______________
____
____

(Please provide similar data for Car Type 2, 3 and 4 on a separate sheet, if applicable.)

2. Details of Low Current Short-Circuit Fault Experience on Trains or Cars

(Please review your experience with onboard electrical faults over the past six years. If the relevant low current faults you have experienced can be grouped, please report experience by grouping. If not report on individual incidents. A copy of your response to our earlier questionnaire is included for reference.)

For each major incident or group of incidents, please provide the following:

Train Incident, Group 1

o Briefly describe the nature of the fault or group of faults: ______________
____
____

*No. of such incidents since July 1, 1982 ______________
*No. of such incidents between July 1, 1976 and July 1, 1982 ______________
Only one incident described Date ______________

o Type of train or car involved ______________
(Refer to your earlier response)

a. Functional location of fault (Check one)
☐ Auxiliary Systems ☐ Track/Ancillary System

☐ Heating, Ventilating and Air Conditioning System

☐ Cable to car-body short ☐ Other (Specify) ______________
☐ Loose positive current collector shoe
☐ Arc Chute to car body short
☐ Piece or component dragging and contacting the contact rail

b. Where was the train when the incident occurred?

☐ Station At grade, above grade or in open cut (circle what applies)
☐ Tunnel
☐ Yard
☐ Other (Specify) ______________________

c. Unsafe conditions resulted (check all appropriate boxes).

☐ Fire ☐ Toxic Fumes ☐ Smoke

☐ Delay in tunnel between stations ☐ Delay between stations not in tunnel

☐ Other (Specify) ______________________

d. Was there any reported effect on

Signal System ☐ Yes ☐ No If "Yes", please explain ______________
____

Communication System ☐ Yes ☐ No If "Yes", please explain ______
____

e. Was low current short-circuit detection equipment installed when the incident(s) occurred? ☐ Yes ☐ No

If "Yes", did equipment perform satisfactorily? ☐ Yes ☐ No
If "No", please explain: ______________________
____

f. Is information available about the electrical characteristics of this fault (current, rate-of-rise, value of current, voltage drop, etc.)? If yes, please give particulars (attach sheet if necessary). ______________
____
____

3. Details of Low Current Short-Circuit Detection Equipment Installed as Part of Tractiion Power Supply

Describe equipment now in service:
Manufacturer ______________ Type ______________ Model ______________
Principle of Operation ______________________
____
Rating ______________________
Other pertinent information ______________________
Evaluation of suitability, consistency of performance, etc. ______________
____
____

(If more than one type of equipment in use, please attach sheet.)

4. Details of Low Current Short-Circuit Fault Experience With Traction Power Distribution System

(Please review your experience with traction power system faults over the past six years. If the relevant low current faults you have experienced can be grouped, please report experience by grouping. If not, report on individual incidents.)

For each major incident or group of incidents, please provide the following:

Traction Power Incident, Group I

o Briefly describe the nature of the fault or group of faults: ________________
____
____

No. of such incidents since July 1, 1982 ____________

No. of such incidents between July 1, 1976 and July, 1982 ____________
☐ Only one incident described Date ____________________

Location of Fault:
☐ In Station ☐ In Yard ☐ In Tunnel

☐ At grade, above grade or in open cut (circle what applies)

☐ Other (Specify) ____________________________

- o Distance from substation __________ km Mile (circle one)
- o Distance from gap breaker station ________ km Mile (circle one)
- o Did any unsafe condition result? ☐ Yes ☐ No

  If "Yes", describe briefly ____________________________
  ____

- o Was low current short-circuit detection equipment installed prior to this incident? ☐ Yes ☐ No

  If "Yes", did breakers trip as a result of the fault?
  Substation breaker ☐ Yes ☐ No

  Gap breaker station breaker ☐ Yes ☐ No

  Other (Specify) ____________________________

  Information available about the electrical characteristics of the fault incident or group (current, rate-of-rise of current, voltage drop, other)? If Yes, please give particulars (attach sheet if necessary).
  ____
  ____

  (Please attach sheets for additional fault incident or grouping of incidents.)

5. Do you have additional information or data on this general problem or can you tell us where such information exists? ____________________
____

Thank you. Please return this questionnaire in the envelope provided.

---

*Please use estimated data only if records are not available, but indicate by "Est."

MAIN
1893

CHAS. T. MAIN, INC., Engineers
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262-3200

Date

SUBJECT: Detection of Low-Current Short Circuits

Name & Address
of Equipment Supplier (XYZ)

Attention: Engineering Division

Dear Sir:

Chas. T. Main, Inc. (MAIN) is conducting a research study in the area of low level electrical fault detection on electrified transit and rail systems. We are asking (XYZ), as an electrical equipment supplier to the transit industry, for information about the product line you offer for fault detection applications. If your office is not the appropriate one for this inquiry, would you be so kind as to forward our letter to the right individual in your company?

This work is being performed for the National Academy of Sciences (Subcontract No. TR 43-1), under the National Cooperative Transit Research Program. The results will, of course, be available to you and all other interested parties when the study is complete.

Specifically, our project is concerned with detection of low-current short circuits on board transit vehicles or in the traction power distribution system. Detection of such faults has proved difficult on some transit systems because the current created by many shorts resembles and often lower than train starting currents or the current characteristics associated with power switching, or because the fault may occur at a point remote from a substation. Relays operating on the "rate-of-rise" principle are an important example of specialized type of equipment that has been applied to this problem (but by no means universally adopted). A more complete but nevertheless brief statement of the "low-current short circuit problem" is attached.

NEW YORK, NEW YORK • BOSTON, MASSACHUSETTS • CHARLOTTE, NORTH CAROLINA • PORTLAND, OREGON

Our objective in this project is to assemble relevant information on available equipment and transit experience with the problem and to evaluate the performance and practicability of the equipment and methods that are available and in use. We are also surveying transit system operators concerning their experience and practices and are working in close touch with the American Public Transit Association's Subcommittee on High Resistance Faults.

With this background on our activities, we hope you will be willing to answer the following questions about the equipment you supply.

1. Does (XYZ) offer low-current short circuit detection equipment for transit or electrified rail application:

    a) For installation at tractor power substations?

    b) For installation on board transit cars or locomotives?

    c) For other types of installation?

    Please furnish particulars about such components or systems (principle of operation, technical data, brochures, etc.).

2. What is the current price and estimated cost of installation of the above system or components?

3. Do you offer devices for other applications that have potential application to transit and electrified rail? Please furnish particulars.

4. What transit system or rail systems have installed your equipment? Any particulars you can provide -- which specific components and their specific application on the system -- will be appreciated.

5. Has your organization performed studies of this problem area which are available to us? Copies or references to the open literature would be appreciated.

I might add that MAIN is an Architect and Engineering firm with experience in rail-transit electrification and broad study and research capabilities. We are not an equipment manufacturer.

Your assistance in this important project is greatly appreciated.

Very truly yours,

CHAS. T. MAIN, INC., Engineers

Navin S. Sagar,
Principal Investigator

Attachment

MAIN
1893

CHAS. T. MAIN, INC., Engineers
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262-3200

Date

SUBJECT: Detection of Low-Current Short Circuits

Name & Address of Industry or
Professional Organization (XYZ)

Dear Sir:

We are writing to ask your assistance in connection with a study of low level short circuit detection or high resistance faults on electrified rail systems. We feel that the (XYZ) industry may experience similar problems, and would be very interested in learning of any investigation of the problem or solution for it in the (XYZ) industry of which you may be aware.

If another individual in your organization would be in a better position to respond to this inquiry, we would be appreciative if you could refer our letter to that person.

In brief, many electrical faults or short circuits on rail systems are not detected by conventional equipment, because they occur at a point remote from a substation and the resulting fault current magnitude is quite small (due to high short circuit impedance), or because the fault current resembles or is no larger than the normal starting current of the traction motor. An unsafe condition may easily result.

We have attached a more extensive, but still quite brief, problem statement. Perhaps you can advise us if an analogous electrical problem is receiving attention in your industry.

This project is carried out under contract to the Transportation Research Board of the National Academy of Science. It has been designated as National Cooperative Transit Research Project 43-1, "Detection of Low-Current Short Circuits". As part of the project we are surveying industries such as yours, the equipment suppliers, and transit system operations worldwide. The intent of the study is to find out how transit systems (or other industries) now deal with the low-current short circuit problems, and to evaluate successful approaches for application to United States' systems.

Any assistance you can give us will be greatly appreciated.

Very truly yours,

CHAS. T. MAIN, INC., Engineers

Navin S. Sagar,
Principal Investigator

Attachment

MAIN
1893

CHAS. T. MAIN, INC., Engineers
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262-3200

Date

SUBJECT: Detection of Low-Current Short Circuits

Name and Address of
Individual Firms (XYZ)

Attention: Engineering Department

Dear Sir:

We are writing to ask your assistance in connection with a study of short circuit detection on electrified rail systems. We feel that the (XYZ) industry may experience similar problems, and would be very interested in learning of any experience with a similar problem in your firm, perhaps in connection with low level or high resistance faults.

If another individual in your organization would be in a better position to respond to this inquiry, we would be appreciative if you could refer our letter to that person.

In brief, many electrical faults or short circuits on rail systems are not detected by conventional equipment, because they occur at a point remote from a substation and the resulting current is quite small (due to high short impedance), or because the fault current resembles or is no larger than the normal starting current of the traction motor. An unsafe condition may easily result.

We have attached a more extensive, but still quite brief, problem statement. Perhaps you can advise us if an analogous electrical problem is receiving attention in your industry.

This project is carried out under contract to the Transportation Research Board of the National Academy of Science. It has been designated National Cooperative Transit Research Project 43-1, "Detection of Low-Current Short Circuits". As part of the project we are surveying firms such as yours and transit system operations worldwide. The intent of the study is to find out how transit systems (or other firms) now deal with the low-current short circuit problem, and to evaluate successful approaches for application to United States systems. We also, of course, are searching for relevant experience outside the transit industry.

Any assistance you can give us will be greatly appreciated.

Very truly yours,

CHAS. T. MAIN, INC., Engineers

Navin S. Sagar,
Principal Investigator

Attachment

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PROBLEM STATEMENT

Summary of Objectives

When typical starting traction current characteristics are compared with the low level fault current characteristic, it is often noted that the profile of the latter is uniformly lower, mainly due to the system short circuit impedance. As a result, such faults are often not detected, with potentially serious consequences to safety and operation.

The objectives of the study are to identify the causes and/or situations resulting in low level faults and the most commonly applied methods of detecting and protecting against them by:

(a) Surveying transit properties worldwide about their experience.

(b) Surveying industry organizations and industries to learn of similar problems and solutions in other industries.

(c) Surveying of equipment suppliers to learn of their efforts and equipment offered for low current fault detection.

Based on the information gathered in the surveys, the study will identify and evaluate detection methods and equipment for enhancing transit system safety in the United States.

General Description

Many transit systems experience certain electrical faults (short circuits) that are difficult to detect because the short-circuit current is no larger, if as large, as currents arising in normal operations.

"Low level" faults may have current characteristics resembling the characteristics associated with the train starting or with power switching operations, which make it difficult to detect such faults. Detection becomes more difficult for low level remote faults as substation capacity and spacing between substations increases. Nondetection of such faults permits arcing, possibly resulting in fire and jeopardizing the safety of the riding public and operation of the system.

Devices presently in use in the traction power system and transit vehicles can adequately detect and clear or respond to fault currents due to overloads or heavy short circuits. The detection of fault currents of magnitude less than feeder breaker trip setting is the problem, however. Such faults are not frequent, but they may be extremely hazardous if they remain undetected when they occur.

Subsystems or components and situations that have been noted as the location of low current short-circuit problems include the following:

Faults Involving Transit Vehicles

- Train control system (cam or chopper)
- Dynamic rheostative braking system
- Commutator motor
- Motor-alternator set motor
- Failure of internal component of auxiliary or HVAC system
- Arcing while passing through a crossover
- Cable to car body short
- Relay to car body short
- Arc from arc-chute to car body
- Positive current collector shoe torn loose
- Piece or component dragging and contacting third rail
- Rubber tire blowout (for system with rubber tires)

Faults on the Traction Power and Distribution System

- Arcing faults in the dc cables at trackside sectionalizing switches or in manholes or cable vaults
- Broken trolley wire in contact with car,running rails or ground
- Faults due to switching a traction power substation onto an already energized system

- A foreign object causing arcing between the contact rail and ground (at a point remote from the substation)

Conditions Which Increase the Difficulty of Detecting Low Current Faults

- Transients caused by switching of equipment on utility high tension line
- Crowding of trains per feeding section
- Simultaneously accelerating trains in opposite directions in a feeding section closer to the substation

Specific Situations Involving High Impedance Faults or Arcing Faults

- Fault developed and persisted between contact rail, cast iron tunnel liner and negative running rail resulted in a four hour delay during morning rush hour

- Fault involving contact rail and a base slab, scorching the subway wall and damaging a car body

Parameters and Characteristics of Fault Currents

Fault current waveshape and magnitude depends on the effective resistance (R) and effective reactance (X) of the circuit. These parameters are easy to calculate when the overload fault occurs near to or at the substation. However, the magnitude and shape of the current resulting from a low level fault at a location remote from the substation depends on the additional R and X values of the circuit outside of the substation. These additional parameters consist of resistance and reactance of contact rail or catenary section, negative return system, tracks and impedance bond and track configurations. If the fault is of the arcing type, the arc impedance will also affect the fault level. Rectifier substations with built-in reserve capacity for future generation may have high speed dc breakers of higher trip ratings designed for local fault levels. A local fault has not only a high steady state value but an even higher transient asymmetric first cycle peak current. A high trip setting at the track feeder will not, however, interrupt the circuit for a low level fault which may be arcing at a point remote from the substation.

The higher capacity dc feeder breakers presently in use may well be capable of sustaining local faults indefinately. With substations rated for NEMA extra heavy traction duty cycle (150% of normal rating for 2 hours, peaks of 300% for 60 seconds and 450% for 15 seconds), the problem of distinguishing between the normal traction load current and a remote or low level fault current of a similar magnitude is not easy to resolve.

APPENDIX B

SUMMARY OF RESPONSES FROM TRANSIT SYSTEMS

LEGEND

U/G	Underground
E	Elevated
S/S	Subway—Surface Line
C	Catenary
T	Contact Rail
LCF	Low-Current Fault
LCFD	Low-Current Fault Detection
EXP/D?	Was an arcing fault or LCF experienced by the system?
D/S?	Was an arcing fault or LCF detected successfully?
TU	Tunnel
ST	Station
F	Fire
TF	Smoke
CS	Casualty
D	Delay
TPS	Traction power substation
GBS	Gap breaker station
COMM	Communications

MAIN
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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 5819-1 Sheet B-2 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
WIENER STADTWERKE VERKEHRSBETRIEBE (WSV) WIEN, AUSTRIA		X				100	900V	525V	750V		X	X		• GROUNDED OVERHEAD STRUCTURES • UNGROUNDED RETURN CURRENT SYSTEM • DOUBLE END FED SYSTEM • 0.8 KM LONG INDIVIDUAL ELECTRIFIED SECTION • 3.15 MVA CAPACITY OF THE TPS • EACH TPS WITH 6 DC FEEDER BREAKERS • 5 MINUTE HEADWAYS DURING BOTH RUSH HOUR AND NON-RUSH HOUR PERIODS • 2 TO 3 CARS/TRAIN MAXIMUM • 2 MOTORS/CAR • I_{ST} = 340 AMPS/MOTOR I_{RUN} = 240 AMPS/MOTOR • CAR MFR. - BOMBARDIER-ROLAX-WIEN • CONTROL - CAM CONTROLLED
	X			42	8	50	900V	525V	750V		X		X	• UNGROUNDED RETURN CURRENT SYSTEM • DOUBLE END FED SYSTEM • 2 KM LONG INDIVIDUAL ELECTRIFIED SECTION • 6.3 MVA CAPACITY OF THE TPS • EACH TPS WITH 4 DC FEEDER BREAKERS • 3 MINUTE RUSH HOURS AND 5 TO 8 MINUTE NON-RUSH HOUR HEADWAYS • 2 TO 3 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} = 350 AMPS/MOTOR I_{RUN} = 240 AMPS/MOTOR • CAR MFR. - SGP - WIEN • CONTROL - CAM CONTROLLED

MAIN 1803

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-3 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
WSV WIEN AUSTRIA	X		X		NO DETAILS PROVIDED FOR LIGHT RAIL											X		X		NO DETAILS PROVIDED FOR LIGHT RAIL													
					X	X						FOR METRO TRACTION MOTOR FAILURE ●OVER STRIKE ON BRAKE RESISTOR ●CABLE FAILURE	●CABLE TO CAR BODY SHORT ●AUXILIARY SYSTEM ●TRACK/ ANCILLARY SYSTEM	FOR METRO AEG MFRD. GEAMATIC TYPE DIFF. PROTECTION	MONITORS THE DIFFERENTIAL OF PRIMARY CIRCUIT & MAX. CURRENT ●DETECTS RELATIVELY LOWER THAN HEAVY GROUNDED S/C ●AEG EQUIP. PERFORMS SATISFACTORILY.	NO DETAILS PROVIDED FOR METRO											●SIEMENS 3UB51 RATE-OF-RISE CURRENT ASSEMBLY ●BBC LINE FAULT DETECTOR DDL-ACA-11	●PROVIDED TWO PAPERS PUBLISHED BY BBC. ●PROVIDED VIENNA UNDERGROUND METRO CONST. ARTICLES ●3UB51 RATED @20A/mS DDL RELAYS BEING TESTED EVERY ALTERNATE YEAR WITH S/C CURRENT <6 kA		X		X	
								D	OTHER													D	OTHER										
								X	BOTH IN TUNNEL & AT GRADE BETWEEN STATIONS																								

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-1 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
NEW YORK CITY TRANSIT AUTHORITY (NYCTA) NEW YORK, N.Y., USA	X			60	30	10	750V	600V			X		X	• UNGROUNDED RETURN CURRENT SYSTEM • ONE MILE (APPROX.) LONG INDIVIDUAL ELECTRIFIED SECTION • UP TO 80 YRS. OLD EQUIPMENT . • TWO TPS PER ELECTRIFIED SECTION • DOUBLE END FED AND CENTER FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GBS • 4000 AMPS FDR. BKR. RATINGS • 2 MINUTE RUSH HOUR HEADWAYS • 8 TO 10 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} (VARIES) BETWEEN 295 AND 500A I_{RUN} (APPROX.) 300A • UP TO 40 YR. OLD CARS • CAR MFRS. - A.C.F., BUDD CO., ST. LOUIS CAR CO. AND PULLMAN • CONTROL - CAM CONTROLLED (MAGNETIC AND PNEUMATIC) AND CHOPPER CONTROLLED

MAIN 1803

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-5 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
NYCTA New York USA	X			X	*									NO DETAILS PROVIDED		X		X		*							NYCTA USES • LEAD SHEATH PROTECTION SYSTEM (POTENTIAL & CURRENT) • LOAD MEASURING SYSTEM AND EXERCISES • VISUAL INSPECTION BY OPERATING PERSONNEL		*				• QUESTIONNAIRE PART. II NOT RETURNED, HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED. • IN A SEPARATE RESPONSE NYCTA REPORTED LCFD ON-BOARD ALL THEIR TYPES OF CARS.
								D	OTHER													D	OTHER										
																											NO OTHER DATA OR INFORMATION PROVIDED						

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-5 of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
BERLINER VERKEHRS-BETRIEBE (BVG) BERLIN FEDERAL REPUBLIC OF GERMANY	X			83	8	9	900V	525V			X		X	● GROUNDED RETURN CURRENT SYSTEM ● 1 TO 5 KM LONG INDIVIDUAL ELECTRIFIED SECTION ● 1 TO 2 TPS PER ELECTRIFIED SECTION ● 2 TO 10 MW CAPACITY OF THE TPS ● EACH TPS WITH 2 DC FEEDER BREAKERS ● 1 TO 25 YR. OLD EQUIPMENT ● SINGLE END AND DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES ● 2½ MINUTE RUSH HOUR HEADWAY 3 MINUTE NON-RUSH HOUR HEADWAY ● 6 TO 8 CARS PER TRAIN ● 2 MOTORS/CAR ● I_{ST} (VARIES) BETWEEN 160 TO 200 AMPS/MOTOR I_{RUN} (VARIES) BETWEEN 112 TO 150 AMPS/MOTOR ● CAR MFRS. - ORENSTEIN U. KOPPEL, WAGGON-UNION, DWM ● CONTROL - CAM CONTROL, CHOPPER CONTROL AND ROTATING CURRENT DEVICE

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-7 of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
BVG BERLIN FEDERAL REPUBLIC OF GERMANY	X		X		← * →									• OVER-CURRENT COUNTER OR SWITCHER • DIFFERENTIAL RELAY AND OVER-CURRENT COUNTER OR SWITCHER IN ENCLOSURE ← NO OTHER** DATA OR INFORMATION PROVIDED →			X		X	← * →							A DEVICE ON THE dI/dt PRINCIPLE WITH Δ I AND TIME MONITORING WITH ADJUSTMENT ← NO OTHER** DATA OR INFORMATION PROVIDED →		← * →				• QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED. • **INTENDS TO START TESTING OF LCF'S IN NEW 7 KM SECTION ONCE OPERATION COMMENCES.
								D	OTHER													D	OTHER										

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-8 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MINISTRERIO DE OBRAS PUBLICAS, DIRECCIÓN GENERAL DE METRO (MCMS) SANTIAGO DE CHILE, CHILE	X (WITH RUBBER TIRES)			90	-	10	900V	600V			X		X	● UNGROUDED RETURN CURRENT SYSTEM ● 1 TO 3.2 KM LONG INDIVIDUAL ELECTRIFIED SECTIONS ● 1 TO 2 TPS PER ELECTRIFIED SECTION ● 4.5 MVA CAPACITY OF THE TPS ● EACH TPS WITH 2 DC FEEDER BREAKERS ● 9 YR. OLD EQUIPMENT ● DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAP BREAKER STATIONS ● 2½ MINUTE RUSH HOUR HEADWAY 4 MINUTE NON-RUSH HOUR HEADWAY ● 5 CARS PER TRAIN 4 MOTORS/CAR ● I_{ST} = 900 AMPS I_{RUN} = 400 AMPS ● CAR MANUFACTURERS - ALSTHOM FRANCE ● CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-9 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																				COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN																	IN TRACTION POWER SYSTEM															AFFECTED				
	LOW CURRENT FAULT															DETAILS OF LCFD DEVICE		LCF													DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN						CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN						CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS	D	OTHER					Y	N	Y	N	TPS	GBS	F	TF	SM	CS	D	OTHER				Y	N	Y	N	
MCMS SANTIAGO DE CHILE, CHILE	X		X		NOT REPORTED AT MCMS NORMALLY								DIFF. RELAY ON-BOARD LET THE LEAD CAR OUT OF SERVICE	•POWER RESISTANCES WERE INVOLVED •THE METALLIC DUST MAKES A CONTACT WITH A CAR BODY	•TRACTION SYSTEM WAS INVOLVED	•DIFFERENTIAL CURRENT RELAY, COMPARES THE INPUT CURRENT WITH OUTPUT CURRENT. MFRD. BY SERVO-CONTACT.	•STATED THAT IT OPERATES EVERY TIME THERE IS A LEAKAGE OF CURRENT. •IT DETECTS MIN. OF 80± 10A BETWEEN INPUT & OUTPUT CURRENT	X		X		0.1KM	0.1KM	NO DATA PROVIDED BUT STATED THAT NO UNSAFE CONDITION RESULTED						•ARC RESULTS WHEN POSITIVE CURRENT COLLECTOR SHOE LEAVES THE CONTACT RAIL. •OCCURRED AT GRADE AND IN YARD.	BBC - SECHERON TYPE PCC E67aE WORKS ON dI/dt PRINCIPLE. THE DEVICE COUNTS THE TIME (t_o) WHICH THE dI/dt GOES ABOVE A MINIMUM PRESET LEVEL TIME t_s THE LCF GETS DETECTED WHEN $t_o > t_s$	MCMS CLAIMED THAT "THERE EXISTS NO FAULTS WHICH HAD NOT BEEN DETECTED BY THIS DEVICE."	X *			X	*SIGNAL SHOWS THAT THE LEAD CAR IS OUT DUE TO THE PROBLEM ON-BOARD CAR FAULT. •MCMS EXPERIENCED THAT THE CHARGE OF CONDENSERS USED TO INJECT SIGNALS OR CARRIERS IN POSITIVE RAILS LOOKED LIKE SHORT CIRCUITS FOR THE DEVICE WHEN THEY ARE PLACED NEARER TO A TPS. •PROVIDED 2 REPORTS ON LCF PROTECTION.

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-10 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
COMPAÑIA METROPOLITANO DE MADRID (CMM) MADRID, SPAIN	X			100	-	-	720V	420V	600V		X	X		● OVERHEAD CATENARY SUPPORT STRUCTURES ARE CONNECTED TO RUNNING RAILS ● UNGROUNDED RETURN CURRENT SYSTEM ● 4 KM LONG ELECTRIFIED SECTION ● ONE TPS PER ELECTRIFIED SECTION ● 6 MW CAPACITY OF THE TPS ● 10 YR. OLD EQUIPMENT ● SINGLE END AND CENTER FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAP BREAKER STATIONS ● AVERAGE 5 DC FEEDER BREAKERS PER TPS ● 2½ MINUTE RUSH HOUR HEADWAY 5 MINUTE NON-RUSH HOUR HEADWAY ● 2 CARS/TRAIN ● 2 TO 4 MOTORS/CAR ● I_{ST} (VARIES) BETWEEN 110 AMPS TO 570 AMPS I_{RUN} (VARIES) BETWEEN 130 AMPS TO 388 AMPS ● CAR MFRS. - CAF, S.E.C. NAVAL ● CONTROL - CAM CONTROL AND CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-11 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
CMM MADRID, SPAIN	NO RESPONSE				← * →									● FUSES ● MAGNETICALLY HELD INTERRUPTORS NO OTHER DATA OR INFORMATION WAS PROVIDED		X		X		← * →							●Δ 1 DETECTION USING BBC - SECHERON MANUFACTURED DDL-ACA-11 DEVICE	NONE PROVIDED	← * →				QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-1 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOCIETE DU METRO LEGER DE TUNIS (CMLT) TUNIS, TUNISIA		X				100	900V	450V	-		X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 10 KM ELECTRIFIED SECTION ● 2 TPS PER ELECTRIFIED SECTION ● 4 TO 4.6 MW CAPACITY OF THE TPS ● DOUBLE END FED SYSTEM ● CMLT USES GAP BREAKER STATIONS ● EACH TPS AND EACH GAP BREAKER STATION HAS 4 DC FEEDER BREAKERS ● 6 MINUTE RUSH HOUR HEADWAY 12 MINUTE NON-RUSH HOUR HEADWAY ● 1 CAR PER TRAIN ● 4 MOTORS/CAR ● I_{ST} = 400A I_{RUN} = 250A ● CAR MANUFACTURER - SIEMENS MAN

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-13 of B-111
By. N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th><th colspan="4" rowspan="2">AFFECTED</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNCTIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>GBS</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td>CMLT
TUNIS
TUNISIA</td><td>X</td><td></td><td></td><td>X</td><td colspan="9">*</td><td>●FUSES
●DIFFERENTIAL RELAYS
●BREAK-IN-JUNCTION POTENTIAL DEVICE</td><td></td><td>X</td><td></td><td></td><td>X</td><td colspan="7">*</td><td>●NO DEVICE IS IN USE NOW</td><td>●PLAN TO TEST AND USE DDL RELAYS MFRD. BY BBC - SECHERON</td><td colspan="4">*</td><td>●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">NO OTHER DATA OR INFORMATION PROVIDED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

MAIN 1803

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
CIE DU METRO DE LILLE (COMELI) LILE FRANCE		X		65	20	15	950V	640V			X		X	● NEGATIVE RAILS ARE GROUNDED SEPARATELY ● 3 KM LONG ELECTRIFIED SECTION ● MAXIMUM 2 TPS PER ELECTRIFIED SECTION ● 15 MW CAPACITY OF TPS ● 50% OF THE LINE HAS 3 YEARS OLD EQUIPMENT ● CENTER FED SYSTEM ● COMELI USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAP BREAKER STATIONS ● 1 DC FEEDER BREAKER PER EACH TPS AND GAP BREAKER STATION ● 5800 AMP RATING OF EACH DC FEEDER BREAKER ● 1 1/2 MINUTE RUSH HOUR HEADWAY 6 MINUTE NON-RUSH HOUR HEADWAY ● 2 CARS/TRAIN ● 2 MOTORS/CAR ● I_{ST} = 550 AMPS ● CAR MFR - C.I.M.T. ● CONTROL - CHOPPER CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-15 of B-18
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
COMELI LILLE FRANCE	ARCING FAULTS NOT EXPERIENCED				← * →									• GROUND DIFFERENTIAL RELAY ← NO OTHER DATA OR INFORMATION PROVIDED →		X		X		← * →							• LOW LEVEL FAULT DETECTORS BY BBC-SECHERON ← NO OTHER DATA INFORMATION PROVIDED →		← * →				• QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-16 of B-111
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
HAMBURGER HOCHBAHN AG (HHA) HAMBURG, FEDERAL REPUBLIC OF GERMANY	X			35	5	60	900V	525V	750V		X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 3.2 KM LONG ELECTRIFIED SECTION ● 23 TPS PER 90 KM LONG ELECTRIFIED SECTION ● 7.5 MW CAPACITY OF EACH TPS ● 6 TO 18 YR. OLD EQUIPMENT ● DOUBLE END FED SYSTEM ● EACH TSP WITH 3 TO 5 DC FEEDER BREAKERS ● 3150 AMP RATING OF EACH DC FEEDER BREAKERS ● USES CONTACT RAIL DISCONNECT SWITCHES ● 2.5 TO 5 MINUTE RUSH HOUR HEADWAY ● 10 MINUTE NON-RUSH HOUR HEADWAY ● 8 TO 9 CARS/TRAIN ● 2 TO 8 MOTORS/CAR ● I_{ST} (VARIES) BETWEEN 218 AMP AND 240 AMP I_{RUN}(VARIES) BETWEEN 180 AMP AND 209 AMP ● CAR MFRS. - DÜWEG, SIEMENS, AEG, LHB, KIEPE ● CONTROL - CAM AND CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT – 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-17 of B-111
By N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th><th colspan="4" rowspan="2">AFFECTED</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th></tr>
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<tr><td>HHA HAMBURG FEDERAL REPUBLIC OF GERMANY</td><td colspan="4">ARCING FAULTS NOT EXPERIENCED</td><td colspan="9">← NO SUCH DATA WAS RECORDED, THEREFORE THERE WERE NO RESPONSES →</td><td colspan="2">NO DEVICE INSTALLED ON-BOARD TRAIN AT THE PRESENT TIME</td><td colspan="4">ARCING FAULTS NOT EXPERIENCED</td><td colspan="7">← NO SUCH DATA WAS RECORDED, THEREFORE THERE WERE NO RESPONSES →</td><td>NO DEVICE INSTALLED AT THE PRESENT TIME</td><td>•REPORTED THAT THE FOLLOWING GERMAN COMPANIES MFR. LCFD DEVICES:
-SIEMENS
-AEG FRANKFURT</td><td colspan="4">NOT RESPONDED TO</td><td>•AWARE & CONCERN OF LCF
•PLAN TO PURCHASE dI/dt EQUIPMENT</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-12 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
LINZER ELEKTRIZITÄTS-FERNWÄRME-UND VERKEHRSBETRIEBE AG (ESG) LINZ, AUSTRIA		X		NOT RESPONDED TO			720V	560V			X	X		• GROUNDED RETURN CURRENT SYSTEM • 14 KM ELECTRIFIED SECTION • 7.04 MW CAPACITY OF EACH TPS • 6 TPS PER ELECTRIFIED SECTION • 2 TO 27 YR. OLD EQUIPMENT • SINGLE, DOUBLE END AND CENTER FED SYSTEM • EACH TPS WITH 4 DC FEEDER BREAKERS • 4 MINUTE RUSH HOUR HEADWAY 6 TO 7½ MINUTE NON-RUSH HOUR HEADWAY • 1 CAR/TRAIN • 2 MOTORS/CAR • I_{ST} (VARIES) BETWEEN 100 AMPS AND 350 AMPS/MOTOR • CAR MFR. - ROTAX - BOMBARDIER, SGP • CONTROL - CAM, CHOPPER AND MAGNETICALLY CONTROLLED CARS

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-10 of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE						
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
ESG LINZ AUSTRIA	X ARCING FAULTS NOT EXPERIENCED			X	*									NO DATA OR INFORMATION PROVIDED		X		NOT RESPONDED TO		*							•dI/dt TRIPPING MECHANISM NO DATA OR INFORMATION PROVIDED		*				•QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
ÜSTRA HANNOVERSCHE VERKEHRSBETRIEBE AG (ÜSTRA) HANNOVER FEDERAL REPUBLIC OF GERMANY		X					720V TO 770V	420V			X	X		• 2-LINE ISOLATED CATENARY SYSTEM • GROUNDED RETURN CURRENT SYSTEM • 2 KM LONG ELECTRIFIED SECTION (AVG.) • 1 TO 3.5 MW CAPACITY OF EACH TPS • 0 TO 30 YEARS OLD EQUIPMENT • 1 TO 2 TPS PER ELECTRIFIED SECTION • SINGLE END AND DOUBLE END FED SYSTEM • USED GAP BREAKER STATION • 2 TO 4 DC FEEDER BREAKERS PER GAP BREAKER STATIONS • 4 TO 6 MINUTE RUSH HOUR HEADWAY 5 TO 15 MINUTE NON-RUSH HOUR HEADWAY, • 1 TO 3 CARS/TRAIN • 2 TO 4 MOTORS/CAR • I_{START} VARIES BETWEEN 280 AMPS AND 550 AMPS • CAR MFRS - DÜWEG, LHB, SIEMENS, AEG, KIEPE • CONTROL - CHOPPER CONTROL AND HAND CONTROL OR MANUAL CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-21 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
ÜSTRA HANNOVER FEDERAL REPUBLIC OF GERMANY	X			X	← * →									← NO OTHER DATA OR INFORMATION PROVIDED →		X		X		← * →							•USES RELAY WORKING ON di/dt PRINCIPLE. NO OTHER DATA OR INFORMATION PROVIDED		← * →				☛ QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										
																							• CABLE DAMAGED										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-[illegible] of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
VERKEHRSBETRIEBE ZÜRICH (VBZ) ZÜRICH, SWITZERLAND		X				100	720V	420V			X	X		• CATENARY OVERHEAD STRUCTURES ARE ISOLATED • UNGROUNDED RETURN CURRENT SYSTEM • APPROXIMATELY 1 TO 2 KM LONG ELECTRIFIED SECTION • 0.8 TO 4.5 MW CAPACITY OF EACH TPS • 1 TO 10 YR. OLD EQUIPMENT • 1 TPS PER ELECTRIFIED SECTION • 3 TO 20 DC FEEDER BREAKERS PER TPS • 4500A RATING OF EACH DC FEEDER BREAKER • SINGLE END FED SYSTEM • USES GAP BREAKER STATIONS • 1½ TO 6 MINUTE RUSH HOUR HEADWAY 12 MINUTE NON-RUSH HOUR HEADWAY • 2 CARS/TRAIN • 2 MOTORS/CAR • I_{START} = 450 AMPS I_{RUN} = 240 AMPS • CAR MFRS. - SWS/SWP/BBC • CONTROL - CHOPPER CONTROL

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-2[illegible] of B-111

By N. S. SAGAR Date

Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th><th colspan="4">AFFECTED</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="2" rowspan="2">SIGNAL SYSTEM</th><th colspan="2" rowspan="2">COMM. SYSTEM</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNCTIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>CBS</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td>VBZ
ZURICH
SWITZERLAND</td><td></td><td>N</td><td colspan="2">NOT RESPONDED TO</td><td colspan="9">← * →</td><td colspan="2">•AUTOMATIC ISOLATING SAFETY BREAKER POSSIBLY (HSCB)
← NO OTHER DATA INFORMATION PROVIDED →</td><td></td><td>X</td><td colspan="2">NOT RESPONDED TO</td><td colspan="7">← * →</td><td colspan="2">← NO DATA OR INFORMATION PROVIDED →</td><td colspan="4">← * →</td><td>•QUESTIONNAIRE II WAS NOT MAILED AND HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
•COMMENTED IN A LETTER THAT VBZ DOES NOT HAVE LCF PROBLEM AS THE STAFF REGULARLY PERFORMS A VOLTAGE ISOLATION TEST AND THE EQUIPMENT & CABLES DO NOT PASS THEM, THEY REPLACE THEM.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-24 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
ISTANBUL BELEDIYESI ISTANBUL ELEKTRIK TRAMWAY VE TÜNEL ISLETMELERI (IETT) ISTANBUL, TURKEY	X			100			650V	550V			X	X		• CATENARY OVERHEAD STRUCTURES ARE CONNECTED TO RUNNING RAIL • GROUNDED RETURN CURRENT SYSTEM • 1.2 KM LONG ELECTRIFIED SECTION FOR METRO 208 KM LONG ELECTRIFIED SECTION FOR LIGHT RAIL • 30 MW TPS CAPACITY (FOR LIGHT RAIL) • 23 YR. OLD EQUIPMENT • 2 TPS PER ELECTRIFIED SECTION • 450A EACH DC FEEDER BREAKER RATING • USES GAP BREAKER STATIONS • 45 DC FEEDER BREAKERS PER TPS • 60 DC FEEDER BREAKERS PER GBS • INSTEAD OF HEADWAYS THE SPEED IS GIVEN WHICH IS ERRONEOUS • ONE CAR PER TRAIN • ONE MOTOR PER CAR • I_{ST}, I_{RUN} } SEEMS ERRONEOUSLY GIVEN • CAR MFR: ANSALDO SAN GIORGIO • CONTROL: STATED OTHER WITH FA 6220
		X				100	240V				X	X		

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B 25 of B-111
By N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="4">TRANSIT SYSTEM</th><th colspan="18">LOW CURRENT FAULT DATA</th><th colspan="15"></th><th rowspan="4">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="17">ON-BOARD TRAIN</th><th colspan="14">IN TRACTION POWER SYSTEM</th><th colspan="2"></th></tr>
<tr><th colspan="15">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="4">AFFECTED</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNC-TIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th></th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>CBS</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th></th></tr>
<tr><td>IETT
ISTANBUL
TURKEY</td><td>X</td><td></td><td>X</td><td></td><td colspan="9">← * →</td><td colspan="2">BREAKER
← NO OTHER DATA OR INFORMATION PROVIDED →</td><td>X</td><td></td><td>X</td><td></td><td colspan="7">← * →</td><td colspan="2">•RADAR SYSTEM
← NO OTHER DATA OR INFORMATION PROVIDED →</td><td colspan="4">← * →</td><td>•QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
TYNE AND WEAR PASSENGER TRANSPORT EXECUTIVE (TWPTE) NEWCASTLE UPON TYNE, ENGLAND	X			11	3	86	1575V	1200V			X	C		• CATENARY OVERHEAD STRUCTURES ARE CONNECTED TO RUNNING RAIL • UNGROUNDED RETURN CURRENT SYSTEM • MAXIMUM 7 KM LONG ELECTRIFIED SECTION • ONE TPS AT EACH END OF ELECTRIFIED SECTION • 24.5 MW CAPACITY OF TPS • 5 YR. OLD EQUIPMENT • DOUBLE END FED SYSTEM • USES GAP BREAKER STATIONS • 4 DC FEEDER BREAKERS PER TPS • 2000 AMP RATING OF DC FEEDER BREAKER • 3-1/3 MINUTE RUSH HOUR HEADWAY 5 MINUTE NON-RUSH HOUR HEADWAY • 2 CARS/TRAIN • I_{START} = 435 AMPS • CAR MFR. - METRO-COMMELL LTD. • CONTROL - CAM CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B27 of B-111

By N. S. SAGAR Date

Chd Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
TWPTE NEWCASTLE UPON TYNE ENGLAND	ARCING FAULTS NOT EXPERIENCED				← * →									OVERLOAD RELAYS SET AT 580 AMPS ← NO OTHER DATA OR INFORMATION PROVIDED →		X ARCING FAULTS NOT EXPERIENCED		X		← * →							●TIMED OVERLOAD PROTECTION ●EARTH POTENTIAL PROTECTION	●REPORTED THAT LCF TESTS IN CONNECTION TO BKR. & EARTH POTENTIAL WERE PERFORMED ○PROVIDED A GRAPH SHOWING A SHORT CIRCUIT CURVE SUPERIMPOSED ON POWER SYSTEM CHARACTERISTIC CURVE	← * →				●NO FURTHER DETAILS OF THEIR LCF TESTING WAS PROVIDED. ●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-27 of B-111

By N. S. SAGAR Date

Chk. Rev.

	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
TRANSIT SYSTEM	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
ATHENS - PIRAEOUS ELECTRIC RAILWAYS CO. LTD. (A-PER) ATHENS GREECE	X			12		88	660V	420V			X		X	• GROUNDED RETURN CURRENT SYSTEM • 27 KM LONG ELECTRIFIED SECTION • 3.6 MW CAPACITY OF EACH TPS • 11 SUBSTATIONS PER 27 KM SECTIONS • UP TO 2 YR. OLD EQUIPMENT • CENTER FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 2 DC FEEDER BREAKER/TPS • 2000 AMP RATING OF EACH FEEDER BREAKER • 4 MINUTE RUSH HOUR HEADWAY 12 MINUTE NON-RUSH HOUR HEADWAY • 4 TO 5 CARS/TRAIN • 2 TO 4 MOTORS/CAR • I'_{ST} VARIES BETWEEN 600 AMPS TO 1000 AMPS I_{RUN} VARIES BETWEEN 400 AMPS TO 500 AMPS • CAR MFRS. - SIEMENS, MAN, L.E.W. • CONTROL - CAM AND CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
A-PER ATHENS GREECE	X ARCING FAULT NOT EXPERIENCED			X	◄—— * ——►									NO DATA OR INFORMATION PROVIDED		X ARCING FAULTS NOT EXPERIENCED			X	◄—— * ——►							NO DATA OR OR INFORMATION PROVIDED		←— * —→				●QUESTIONNAIRE PART II WAS NOT MAILED HENCE TH DATA IDENTIFIED BY * COULD NOT BE COMPLETED
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-30 of [illegible]
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SAN FRANCISCO MUNICIPAL RAILWAY (MUNI) SAN FRANCISCO, CALIFORNIA, U.S.A.		X		27		73	640V	500V			X	X		● CATENARY OVERHEAD STRUCTURES ARE UNGROUNDED ● UNGROUNDED RETURN CURRENT SYSTEM ● APPROXIMATELY 1.6 KM ELECTRIFIED SECTION ● 750 KW TO 8 MW CAPACITY OF TPS ● 5 YR. OLD EQUIPMENT ● SINGLE END FED AND CENTER FED SYSTEM ● USES GAP BREAKER STATIONS ● 3 TO 4 DC FEEDER BREAKERS/TPS AND 2 DC FEEDER BKR/GBS ● 2000 TO 6000A RATING OF DC FEEDER BREAKER ● 3 MINUTE RUSH HOUR HEADWAY 5 MINUTE NON-RUSH HOUR HEADWAY ● CAR MFR. - BOEING VERTOL ● CONTROL - CHOPPER CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 1819-1 Sheet B-21 of B-41
By N. S. SAGAR Date —
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
MUNI SAN FRANCISCO CALIFORNIA U.S.A.	X		X		← * →									●VEHICLE GROUNDED ← NO OTHER DATA OR INFORMATION PROVIDED →		X		X		← * →							●HSCB WITH RATE-OF-RISE (SURGE DETECTION FEATURE) ●HUMAN VISUAL OBSERVATION ← NO OTHER DATA OR INFORMATION PROVIDED →		← * →				●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED. ●NETWORK MAP OF MUNI SYSTEM WITH THE LOCATIONS, CAPACITY AND NUMBER OF FEEDER BREAKERS IN EACH TPS IS PROVIDED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
METROPOLITAN TRANSIT AUTHORITY (MTA) HOUSTON TEXAS U.S.A.														● A LETTER STATING FOLLOWING RECEIVED - PLANNING A NEW TRANSIT SYSTEM - INTERESTED IN THE SUBJECT SO COULD BE HELPFUL IN FUTURE

MAIN
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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE						
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
								D	OTHER													D	OTHER										

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1
Sheet [illegible] of B-111
By N. S. SAGAR
Date
Chd.
Rev

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UC %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY (RTA) CLEVELAND OHIO USA	X			3		97	600V				X	X		• GROUNDED CATENARY OVERHEAD STRUCTURES • GROUNDED RETURN CURRENT SYSTEM • APPROXIMATELY 2 MILE LONG EACH ELECTRIFIED SECTION • 1.5 MW/TPS • 2 TO 30 YEARS OLD EQUIPMENT. • DOUBLE END FED SYSTEM • 4 DC FEEDER BREAKERS PER TPS • 4500 AMPS RATING OF EACH FEEDER BREAKER • 10 MINUTE RUSH HOUR HEADWAY 20 MINUTE NON-RUSH HOUR HEADWAY • 1 TO 3 CARS/TRAIN • 2 TO 4 MOTORS/CAR • I_{ST} = 485 AMP (FOR METRO) • CAR MFRS - PULLMAN STANDARD, BREDA • CONTROL - CAM CONTROL & CHOPPER CONTROL
		X		1		99	600V				X	X		

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-55 of B-111
By N. S. SAGAR Date
Chd. Rev

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
RTA CLEVELAND OHIO USA	ARCING FAULTS NOT EXPERIENCED				← * →									o HSCB ON DI/DT PRINCIPLE MFRD. BY BBC	NONE	X		X		← * →							● RATE OF RISE RELAYS	NO OTHER DATA OR INFORMATION PROVIDED	← * →				● QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * WAS NOT COMPLETED.
								D	OTHER													D	OTHER										

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-3 of B-11
By N. S. SAGAR Date
Chkd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MASSACHUSETTS BAY TRANSPORTATION AUTHORITY (MBTA BOSTON, MA, U.S.A.	X	X	●STREET CARS ●TRACKLESS TROLLEYS	●VARIES BUT HAS ALL COMBINATIONS AMONG ALL LINES			630V VARIES IN THIS RANGE FOR DIFFERENT LINES	475V			X	X FOR BLUE LINE (METRO) & GREEN LINE LIGHT RAIL & TRACKLESS TROLLEY LINES	X FOR METRO	● GROUNDED CATENARY OVERHEAD STRUCTURES ● UNGROUNDED RETURN CURRENT SYSTEM ● 1.5, 1.8, 3.0, 2.0 MILE LONG ELECTRIFIED SECTIONS (VARIES) ● 2 & 3 MW (VARIES) CAPACITY OF TPS ● AVG. AGE OF TPS EQUIPMENT 4 TO 12 YRS. SOME ARE OLDER ● MAXIMUM 2 TPS/SECTION ● SINGLE AND DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES ● 6, 8, 10 DC FEEDER BREAKERS (VARIES) PER TPS ● 2000 AND 4000 AMPS DC FEEDER BREAKER RATING ● 1, 3, 5, 7 MINUTE RUSH HOUR HEADWAY (VARIES) 5, 10, 20, 30 MINUTE NON-RUSH HOUR HEADWAY (VARIES) ● I_{START} VARIES BETWEEN 0 AND 540 AMPS DEPENDING UPON TYE TYPE OF CAR I_{RUN} VARIES BETWEEN 30 AMPS AND 915 AMPS DEPENDING UPON THE TYPE OF CAR ● CAR MFRS. - HAWKER-SIDDLEY, PULLMAN STANDARD, FLYER INDUSTRIES, BOEING VERTOL ● CONTROL - MAJORITY CAM CONTROL, SOME CHOPPER AND FEW ACCELERATOR CONTROL

MAIN 1803

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-2[illegible] of B-1[illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
MBTA BOSTON, MA U.S.A.	X		X		*									●1 CKT.BKR. ●5 CKT.BKRS ●6 CKT.BKRS ●10CKT.BKRS NO OTHER DATA OR INFORMATION PROVIDED		X			X	*							●NO DEVICE IS USED IN ALMOST 50% OF TPS SYSTEM NETWORK ●REST OF THE 50% HAVE ITERATE-OF-RISE RELAYS.	●FREQUENCY OF LCF's REPORTED VARYING IN 1/DAY TO 10/DAY AND INCREASING ●PRESENTLY USING di/dt RATE-OF-RISE DEVICE DOES NOT SEEM ADEQUATE.	*				●DATA FOR 11 DIFFERENT TYPES OF CARS HAVE BEEN PROVIDED THROUGHOUT. ●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B 39 of B-111
By N. S. SAGAR Date
Chkd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UC %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
CHICAGO TRANSIT AUTHORITY (CTA) CHICAGO ILLINOIS USA	X			10	54	36	650V	600V	600V		X	X	X	• GROUNDED OVERHEAD CATENARY STRUCTURES • UNGROUNDED RETURN CURRENT SYSTEM • AVERAGE 2.2 MILE LONG EACH ELECTRIFIED SECTION • 2 TO 2.5 MW CAPACITY OF EACH TPS • EQUIPMENT 1 TO 23 YEARS OLD • 2 TPS/ELECTRIFIED SECTION • SINGLE AND DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT AS WELL AS GAP BREAKER STATIONS • 4000 AMPS RATING OF DC FEEDER BREAKER • 4 FEEDER BREAKERS/TPS & 5 FEEDER BREAKERS/GBS • 2 1/2 TO 4 1/2 MINUTE RUSH HOUR HEADWAY • 15 TO 30 MINUTE NON-RUSH HOUR HEADWAY • 2 TO 8 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 220 AMPS to 624 AMPS/CAR I_{RUN} = 350 AMPS • CAR MFRS. - ST. LOUIS, PULLMAN-STANDARD, BUDD, BOEING VERTOL • CONTROL - MAJORITY CAM CONTROL SOME WITH ACCELERATOR CONTROL (PCC TYPE).

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-39 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
CTA CHICAGO ILLINOIS USA	X	ARCING FAULTS DID NOT EXPERIENCED		X	X		•AT GRADE •IN STREETS	X		X		•SHOE TIE CABLE GROUNDS •PROPULSION WIRING GROUNDS	•CABLE TO CAR BDY TO TRUCK SHORT	NONE	NONE	X		IN DOUBT IF THEY GET DETECTED		NO DATA OR INFORMATION PROVIDED							•RATE OF RISE/TIME DEVICE 76T MFRD BY ITE •CONTINUOUSLY ADJUSTABLE	•RATING VARIES W/ SECTIONS •EACH SEC. IS SET SEPARATELY FOR PERFORMANCE	NOT RESPONDED TO				•SUGGESTED INVESTIGATING PILOT WIRING USED BY LIRR
								D	OTHER													D	OTHER										
								X	•DELAYS IN TUNNEL •DELAYS AT GRADE BETWEEN STATIONS																								

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MONTREAL URBAN COMMUNITY TRANSPORT COMMISSION (CTCUM) MONTREAL, QUEBEC	X WITH RUBBER TIRES			100			950V	600V	750V		X		X	● RUBBER TIRED METRO WITH SEPARATE POSITIVE AND NEGATIVE CONTACT RAILS AND RUNNING RAILS WITH A DEDICATED CONCRETE RUNWAY. ● SYSTEM SOON WILL BE WITH TOTALLY (UNGROUNDED) FLOATING RETURN CURRENT SYSTEM. ● 1.5 KM LONG ELECTRIFIED SECTION ● 2.5 MW CAPACITY OF EACH TPS ● 17 YR. OLD EQUIPMENT ● 2 OR 3 TPS/SECTION ● 4 DC FEEDER BREAKERS PER TPS ● 2600 AMP RATING OF EACH FEEDER BREAKER ● CENTER FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES ● 2'-15" RUSH HOUR HEADWAY 6' NON-RUSH HOUR HEADWAY ● 3, 6, 9 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 500 AMPS (IN SERIES), 1000 AMPS (IN PARALLEL) I_{RUN} = 200 TO 250 AMPS/MOTOR ● CAR MFRS. - CANADIAN VICKERS, BOMBARDIER ● CONTROL - CAM AND CHOPPER CONTROLS

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-11 of B-[illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN																IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
CTCUM MONTREAL QUEBEC CANADA	X		X		X							•FLASH-OVER ON: TRACTION MOTOR, MA SET, FAN MOTOR PER TRACTION RESISTORS CAM CONTROLLERS (HIGH CURRENT CONTACTOR)	•TRACTION MOTOR	•MFRD. BY CANADIAN CONTROLLERS OVERCURRENT CONTROL BREAKING RELAY (QSF) AND OVERLOAD CONTROL FIELD EXCITING RELAY (QSE) •SERVO CONTACT MFRD. FOLLOWING DEVICES: -DIFF. CURRENT DETECTING DEVICE (QDI), -OVERLOAD SERIES RELAY (QIS) -OVERLOAD PARALLEL RELAY (QIP) -OVERCURRENT CONTROL RELAY (QSI) -OVERLOAD CONTROL RELAY (QCI) & -DIFF.	•RATINGS FOR THESE DEVICES ARE PROVIDED WHICH VARIES WITH THE TYPE OF CARS. •OSCILLOGRAM FOR TRAIN UNDER FAULT AT VARIOUS LOCATIONS NEAR SUBSTATIONS ARE PROVIDED. •DEVICES ARE ADDED BY CTCUM TO MODIFY TRAIN.CONTROL CKT. TO AID THE DETECTION & PROTECTION OF LCF PROBLEMS. CURRENT MOTOR DETECTING DEVICE (QDM)	X		X		NOT PROVIDED		NO UNSAFE CONDITION RESULTED				•REINFORCING WIRES IN TIRES CONTACTING THE CONTACT RAIL.	•BBC, SECHERON MFRD. PCC-67a RELAY (SOLID STATE ELECTRONICS) OPERATES ON dI/dt PRINCIPLE	•SETTING 3 MSEC. 800 AMPS •ONE DEVICE SHARES 4 FEEDERS •REPORTED SUITABLE OPERATION AND GOOD PERFORMANCE		X		X	•VERBAL CONVERSATION REPORTED THE FOLLOWING: - PCC-67a ALSO PROTECTS ON-BOARD FAULTS. -THE ON-BOARD LCFD DEVICES WERE ADDED IN TRAIN CONTROL CKT. PRIOR TO INSTALLATION OF PCC-67a. CTCUM CONTINUED KEEPING ON-BOARD LCFD DEVICES AS BACKUP PROTECTOR. -PRESENTLY CTCUM IS EVALUATING BBC-ACAll, SIEMENSE 3UB CERME SOLID STATE LCFD DEVICES TO COMPARE PCC-67a OPERATION FOR THEIR SYSTEM.
								D	OTHER													D	OTHER										
								X	DELAY IN TUNNEL BETWEEN STATIONS													X	DELAY IN TUNNEL BETWEEN STATIONS										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
BAY AREA RAPID TRANSIT DISTRICT (BART) OAKLAND, CALIFORNIA, U.S.A.	X			30	30	40	1200V	750V			X		X	● DIODE GROUNDED RETURN CURRENT SYSTEM ● 2.5 MILE LONG EACH ELECTRIFIED SECTION ● 4, 5, 6, 7, 8 AND 10 MW CAPACITIES OF TPS ● 10 YR. OLD EQUIPMENT ● 1 TO 2 TPS/ELECTRIFIED SECTION ● CENTER FED SYSTEM ● USES CONTACT RAIL DISCONNECTS AND GAP BREAKER STATIONS AS WELL ● 2000, 4000, 6000, 8000 AMPS RATING OF DC FEEDER BREAKER ● 3 MINUTE RUSH HOUR HEADWAY 10 MINUTE NON-RUSH HOUR HEADWAY ● 7 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 700 AMPS (PEAK) I_{RUN} = 340 AMPS (RMS) - RATED RUNNING CURRENT/TRUCK ● CAR MFR. - ROHR ● CONTROL - CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet of

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
BART OAKLAND, CALIFORNIA U.S.A.	X		X		X	X	•YARD •AT GRADE	X	X	X		•TURN ON 'SCR' SHORTED •FLASH-OVER BETWEEN TRACTION MOTOR & MOTOR CONTROL BOX	•TRACTION MOTOR & CONTROL BOX	•FUSES •OVERLOAD RELAYS	•STATED RELAYS MFRD. BY WESTINGHOUSE ELECTRO-MECHANICAL TYPE MODEL VT-377A •RELAY ARM. COIL ENERGIZES AT 1650 +100 -75 (SEEMS OVERLOAD RELAY) •REPORTED EXCELLENT SUITABILITY	X			X	0.01 MILE	0.8† MILE			X		•DC CABLE INSULATION FAILURE LEADING TO SHORT CIRCUIT IN CONDUIT	•NO ANY DEVICE BEING USED PRESENTLY •PLAN TO USE RATE-OF-RISE DEVICES IN NEW EQUIPMENT •JAN. 1984, INSTALLED DIODE AND A SWITCH ACROSS DIODE IN THE TPS NEGATIVE RETURN CKT. TO INDICATE GROUND CURRENT UPON CONDUCTING A DIODE	•STATED THAT MAY BE DUE TO LONG TERM LOW CURRENT, FOUND PART OF THE CONDUCTOR MISSING FROM INSIDE THE INSULATION •AN IEEE PAPER "BART TRACTION MOTOR IMPROVEMENT PROGRAM" WAS FURNISHED.	NOT RESPONDED TO				
								D	OTHER													D	OTHER										
								X																									

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Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet E-[illegible] of B-III
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
TORONTO TRANSIT COMMISSION (TTC) TORONTO, ONTARIO, CANADA	X			19	-	81	650V	450V			X		X	• GROUNDED RETURN CURRENT SYSTEM • 1-2.7 KM (VARIES) LONG ELECTRIFIED SECTION • TOTAL SYSTEM (TP) CAPACITY 154.3 MW • 2 TO 40 YR. OLD EQUIPMENT • 2 TPS/ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 4 TO 12 DC FEEDER BREAKERS PER TPS • 4000 AMP FEEDER BREAKER RATING (METRO) • 2500 AMP FEEDER BREAKER RATING (LIGHT RAIL) • 2'-25" AND 2'-10" RUSH HOUR HEADWAY 3'-42" AND 4'-45" NON-RUSH HOUR HEADWAY • 6 TO 8 CARS/TRAIN - METRO 1 CAR TRAIN - LIGHT RAIL • 4 MOTORS/CAR - METRO 1 TO 4 MOTORS/CAR - LIGHT RAIL • CAR MFRS. - G.R.C. & W. CO., M.L.W. LTD., HAWKER SIDDLEY, (METRO) - C.C. & F. CO., UTDC, F.I. & TTC (LIGHT RAIL) • CONTROL - CAM & CHOPPER (METRO) - MASTER PWR. & BRAKE CONTROLLER AND CHOPPER CONTROL (LIGHT RAIL)
		X				10	650V	450V			X	X		

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet [illegible] of [illegible]

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT												DETAILS OF LCFD DEVICE			LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SH	CS					Y	N	Y	N	TPS	GBS	F	TF	SH	CS				Y	N	Y	N	
TTC TORONTO ONTARIO CANADA	X		X		X	X		X				•ARCING FAULT DEVELOPED & PERSISTED	•CAR BODY	•CURRENT OVERLOAD RELAY •CURRENT OVERLOAD & GROUND FAULT RELAY •LIGHTS WITH LOCK-OUT MECHANISM •CURRENT SENSORS •CHARGED COACH DETECTOR		X			X	AT SUB-STATION FEEDING POINT		X				•ARCING FAULT BETWEEN CONTACT RAIL, RUNNING RAIL & CAST IRON TUNNEL LINER. •ARC ESTABLISHED BETWEEN CONTACT RAIL & GROUND VIA THE SUBWAY STRUCTURE REINFORCED INVERT.	•WESTINGHOUSE MFRD. DC RATE-OF-RISE (D3) RELAY •WESTINGHOUSE INSTANTANEOUS RELAY(S) •MAGNETIC TRIP	•PILOT WIRE SCHEME IS PLANNED FOR NEW SCARBOROUGH LIGHT RAIL LINE IN ADDITION TO ITE-76 •TESTED IN NOV. 83 TESTING BBC-SECHERON DDL-ACA 11 RELAY SUCCESSFULLY FOR ALL EXCEPT HIGH RESISTANCE FAULTS •ADD'L. TESTING IS PLANNED IN THE DEEPEST SECTION OF METRO INVOLVING 3 TPS.	NOT PROVIDED				•STATED THAT EXISTING RELAYS IN TP SYSTEM ARE NOT ADEQUATE
								D	OTHER													D	OTHER										
								X	DAMAGED THE SKIN OF CAR BODY (METRO)					← NO OTHER DATA OR INFORMATION PROVIDED →								X	SCORCHING THE SUBWAY WALL FASCIA										

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
HELSINGIN KAUPUNGIN LIIKENNELAITOS (HKL) HELSINKI, FINNLAND	X			30	10	60	950V	525V			X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● APPROX. 2.5 KM LONG ELECTRIFIED SECTION ● 2.75 MVA CAPACITY OF EACH TPS ● 2 TO 10 YR. O.D EQUIPMENT ● 4 DC FEEDER BREAKERS PER TPS ● 1 TPS/ELECTRIFIED SECTION ● DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECTS ● 4000 AMP RATING OF EACH DC FEEDER BREAKER ● 5 MINUTE RUSH HOUR HEADWAY 10-15 MINUTE NON-RUSH HOUR HEADWAY ● I_{ST} = 150 AMPS/CAR I_{RUN} = 750 AMPS/CAR (MAX.) ● 2, 4, 6 CARS/TRAIN ● 4 MOTORS/CAR ● CAR MFR. - VALMET OY ● CONTROL - INVERTER CONTROL

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Subject NCTRP PROJECT – 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet F-[illegible] of F-[illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																		COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM														AFFECTED					
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM			
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	FU	ST	OTHER	F	TF	SH	CS					Y	N	Y	N	TPS	GBS	F	TF	SH	CS				Y	N	Y	N	
HKL HELSINKI FINNLAND	X		X					X				●CAR FRAME GROUNDED TO THE NEGATIVE RETURN SYSTEM ●FAULTS IN MOTOR INSULATION	●CAR BODY ●TRACTION MOTOR	●EARTH FAULT DETECTOR MFRD. BY KYMI-STROMBERG OY OF HELSINKI MODEL SCEH 1E1 (SEEMS GROUND CURRENT DIFFEREN-TIAL)	MEASURES THE SUM OR DIFFERENCE OF THE INPUT & OUTPUT CURRENT OF THE CAR, WITH THE LOWEST STARTING RATE IS SET AT 5 AMP-TURNS	X	ARCING FAULTS NOT EXPERIENCED			← NO OTHER DATA OR INFORMATION PROVIDED →							●STATED AS dI/dt CONTROL		← NO DATA OR INFO. PROVIDED →				
								D	OTHER													D	OTHER				← NO OTHER DATA OR INFORMATION PROVIDED →						

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SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chk. Rev.

	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
TRANSIT SYSTEM	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
COMPANHIA DO METROPOLITANO DE SÃO PAULO - METRÔ (METRÔ DE SÃO PAULO) SÃO PAULO BRAZIL	X			50	20	30	900V	550V	750V		X		X	• UNGROUNDED RETURN CURRENT SYSTEM • 7-5 TO 25 MW TPS CAPACITY • 4 TO 10 YEAR OLD EQUIPMENT • 17.3 KM LONG ELECTRIFIED SECTION - N/S LINE 11 KM LONG ELECTRIFIED SECTION - E/W LINE (PARTLY COMPLETED) OF 24/KM LINE • 10 TPS FOR N/S LINE 8 TPS OF TOTAL 19 TPS FOR E/W LINE • 4 TO 10 YEARS OLD EQUIPMENT • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 4 DC FEEDER BREAKERS PER TPS • 2 MINUTE RUSH HOUR HEADWAY 3 MINUTE NON-RUSH HOUR HEADWAY • 6 CARS/TRAINS • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 700 TO 750 AMPS I_{RUN} VARIES BETWEEN 375 TO 475 AMPS • CAR MFRS - MAFERSA, COBRASMA • CONTROL - CHOPPER CONTROL

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Client: NATIONAL ACADEMY OF SCIENCES

Subject: NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet [illegible] of [illegible]

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	Y	N	Y	N	
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS								
METRÔ DE SÃO PAULO BRAZIL	X		X		*									• NONE ON SOME CARS o DIFFERENTIAL RELAYS ON SOME oDETECTION IN OPERATORS CABIN FROM CHOPPER CONTROLS.		X		X		*							• BBC-SECHERON DDL RELAY ON DI/DT PRINCIPLE.	NONE					• QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
														NO OTHER DATA OR INFORMATION PROVIDED																			
								D	OTHER													D	OTHER										

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SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOUTHESTERN PENNSYLVANIA TRANSPORATION AUTHORITY (SEPTA) PHILADELPHIA, PENNSYLVANIA, USA	X			62	38	-	750V	450V			X		X	• GROUNDED RETURN CURRENT SYSTEM • 8 TO 2.4 KM ELECTRIFIED SECTION • 6 MW TPS CAPACITY • 4 TO 45 YRS OLD EQUIPMENT • 4000 AMPS DE FEEDER BREAKER • ONE TPS PER ELECTRIFIED SECTION • SINGLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES AND GAP BREAKER STATIONS AS WELL • 4 TO 8 DE FEEDER BREAKER PER TPS • 2 TO 8 DC FEEDER BREAKER PER GBS • 2 MINUTE RUSH HOUR HEADWAY 7.5 MINUTE NON-RUSH HOUR HEADWAY • 1 CAR/TRAIN (LIGHT RAIL), 6 TO 8 CARS/TRAIN (METRO) • 4 MOTORS/CAR • I_{ST} = 350 A (METRO), 500 A (LIGHT RAIL) I_{RUN} = 320 A (METRO), 100 A (LIGHT RAIL) • CAR MFRS - BUDD, KAWASAKI, ST. LOUIS CAR CO.
		X		4	-	96								

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet [illegible] of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																	COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN																IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT														DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
SEPTA PHILA. PA	X (KAWASAKI CARS)		X		← * →									● CKT. BKRS (KAWASAKI CARS ONLY)		X		X		← * →							●di/dt RATE-OF-RISE W/LONG TIME DELAY RELAY.		← * →				● THE QUESTIONNAIRE PART II WAS NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
	X (BUDD & PCC CARS)		X											NO OTHER DATA OR INFORMATION PROVIDED													NO OTHER DATA OR INFORMATION PROVIDED						
								D	OTHER													D	OTHER										

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-10
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
FERROCARRIL METROPOLITANO de BARCELONA, S.A. (FCMB) BARCELONA SPAIN	X			98	2		1650V TO 1250V	1450V TO 1150V	1500V TO 1200V		X	X	X	● GROUNDED CATENANY OVERHEAD STRUCTURES ● GROUNDED RETURN CURRENT SYSTEM ● 2.5 KM LONG ELECTRIFIED SECTIONS ● 6 MW CAPACITY OF EACH TPS ● 5 TO 16 YEARS OLD EQUIPMENT ● 1 TPS PER ELECTRIFIED SECTION ● CENTER FED SYSTEM ● 6 DC FEEDER BREAKER PER TPS ● 3200 AMPS RATING OF EACH FEEDER BREAKER ● USES CONTACT RAIL DISCONNECT SWITCHES ● I_{ST} VARIES BETWEEN 165 AMPS TO 220 AMPS ● I_{RUN} VARIES BETWEEN 137 AMPS TO 180 AMPS ● 3 TO 5 CARS/TRAIN ● 4 MOTORS/CARS ● CAR MFRS – MACOSA, MTM, MAN, BBC, EUSKALDUNA ● CONTROL – CAM CONTROL CARS

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-53 of B-81
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
FCMB BARCELONA SPAIN	X		X		← * →									● DIFFERENTIAL RELAYS ● FUSES oMAGNETO-THERMIC SWITCHES	● STATED DDL RELAYS AT TPS COVERS ON-BOARD FAULTS BUT OPERATES ONLY AT THE DIFFERENCE BETWEEN INPUT & OUTPUT OF APPROX. 60 AMPS	X ARCING FAULTS DID NOT EXPERIENCED		X		← * →							● DDL RELAY DETECTORS NO OTHER DATA OR INFORMATION PROVIDED.		← * →				*QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
METROPOLITAN TRANSIT AUTHORITY (MTA) MELBOURNE, VICTORIA, AUSTRALIA		X STREET CAR				10(	720V	450V			X	X		● CATENARY OVERHEAD STRUCTURES ARE CONNECTED TO RUNNING RAIL. THE RUNNING RAILS ARE ALSO GROUNDED. ● GROUNDED RETURN CURRENT SYSTEM ● 1 TO 3 KM LONG EACH ELECTRIFIED SECTION ● 2 MW TPS CAPACITY ● 2 TO 50 YR. OLD EQUIPMENT ● 1500 AMPS RATING OF EACH DC FEEDER BREAKER ● 2 TPS PER EACH ELECTRIFIED SECTION ● SINGLE END AND DOUBLE END FED SYSTEM ● USES GAP BREAKER STATIONS ● 7 TO 8 DC FEEDER BREAKERS/TPS ● 1 DC FEEDER BREAKER/GBS ● 2 TO 10 MINUTE RUSH HOUR HEADWAY ● 10 TO 30 MINUTE NON-RUSH HOUR HEADWAY ● 1 CAR/TRAIN ● 4 MOTORS/CAR ● I_{ST} VARIES BETWEEN 100 AMPS AND 200 AMPS I_{RUN} VARIES BETWEEN 100 AMPS AND 600 AMPS ● CAR MFRS. - MELBOURNE & METROPOLITAN TRAMWAY BOARD, ASEA & COMMONWEALTH ENGINEERING, AEG TELEFUNKEN

MAIN
1803

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet [illegible] of [illegible]

By N. S. SAGAR Date

Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th><th colspan="4" rowspan="2">AFFECTED</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNC-TIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>GBS</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td>(MTA) MELBOURNE VICTORIA AUSTRALIA</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td><td>●AT STREET</td><td></td><td></td><td></td><td></td><td>●ARCING RELATED TO TRACTION MOTOR FAULTS</td><td>●TRACTION MOTOR ON CAR
●CAR BODY</td><td>●LINE BREAKERS</td><td>SETTINGS ARE: 400 AMPS, 800 AMPS, 1100 AMPS</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td>●BROKEN TROLLEY WIRE IN CONTACT WITH RUNNING RAILS
●SHORT CIRCUIT TO GROUND VIA A CAR BODY</td><td>●RATE OF RISE RELAYS</td><td>SET TO TRIP AT GREATER THAN 1000 AMPS PER MILLI-SECOND</td><td colspan="4">NO DATA PROVIDED</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">← NO OTHER DATA OR INFORMATION PROVIDED →</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">← NO OTHER DATA OR INFORMATION PROVIDED →</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td colspan="3"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td colspan="3">AT STREETS</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOCIETE DES TRANSPORTS INTERCOMMUNAUX DE BRUXELLES (STIB) BRUSSELS, BELGIUM (METRO ONLY)	X			81		19	900V	600V			X		X	• DIODE GROUNDED RETURN CURRENT SYSTEM • 1 KM LONG EACH ELECTRIFIED SECTION • 3 TO 4 MW CAPACITY OF EACH TPS • 7 YR. OLD EQUIPMENT • 2 TPS/ELECTRIFIED SECTION • 7000 TO 11,000 AMPS RATING OF EACH DC FEEDER BREAKER • DOUBLE END FED SYSTEM • DOES NOT USE CONTACT RAIL DISCONNECT SWITCHES OR GAP BREAKER STATIONS • 4 DC FEEDER BREAKERS PER TPS • 2½ MINUTE RUSH HOUR HEADWAY 10 MINUTE NON-RUSH HOUR HEADWAY • 2 TO 4 CARS/TRAIN • 2 MOTORS/CAR • $I_{ST} =$ 930 AMPS TO 1200 AMPS $I_{NOMINAL} =$ 820 AMPS • CAR MFRS. - BN-ACEC, CFC-ACEC • CONTROL - CHOPPER CONTROL

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B 27 of B-111
By N. S. SAGAR Date
Chkd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="17">IN TRACTION POWER SYSTEM</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="4">AFFECTED</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNC-TIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>CBS</th><th>F</th><th>TF</th><th>SM</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td>STIB BRUSSELS BELGIUM (METRO ONLY)</td><td colspan="4">NOT PROVIDED</td><td colspan="7">← DATA NOT PROVIDED →</td><td colspan="2">SEE INSERT</td><td>●BREAKERS
○DIFFEREN-TIAL RELAYS
●VISUAL
NO OTHER DATA OR INFORMATION PROVIDED</td><td>SEE INSERT</td><td>X</td><td></td><td>X</td><td></td><td colspan="7">← DATA NOT PROVIDED →</td><td>●ADJUSTABLE TRIP HSCB WITH di/dc. RELAYS
← NO OTHER DATA OR INFORMATION PROVIDED →</td><td>← NO OTHER DATA OR INFORMATION PROVIDED →</td><td colspan="4">DATA ← NOT → PROVIDED</td><td>ULTRA HSCB IN TPS BEING USED MFRD. BY A.C.E.C. OF BELGIUM. WORKS ON di/dt PRINCIPLE BUT STATED NOT USEFUL FOR LCFD.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

INSERT

- METRO HAD A PROBLEM WITH REMOVAL OF METAL DUST AND COOLING OF TRACTION MOTOR AND SEMICONDUCTORS IN CHOPPER OVERHEATED MAY BE DUE TO BRAKING. PROBLEM OF METALLIC DUST EXTRACTION RESOLVED BY USING COMPRESSED JET AIR.
- FOR MOTOR & CHOPPER, THEY ARE MONITORING CURRENT/CAR & CURRENT/MOTOR AND CURRENT DIFFERENTIAL OF CHOPPER INPUT & OUTPUT (MAX. 50A).
- THEY ALSO USE VISUAL INSPECTION OF CONTROL & CIRCUITS.
- THE THYRISTOR USED TO ACCIDENTALLY GET FIRED AT THE BRAKING SIMULTANEOUSLY. THEY RESOLVED THIS BY DETECTING MAGNETIC FIELD USING "REED TUBE" BY TAKING DIFFERENTIAL OF EITHER INDIVIDUAL CIRCUITS OF CHOPPER OR THE BLOCK OF CIRCUITS WITHIN CHOPPER.

IN DOING SO THEY ALSO EXPERIENCED PROBLEMS SUCH AS:

- OPENING OF CIRCUIT BREAKERS ON CURRENT LESS THAN 50A
- REPETITIVE TRIPOUTS (NUISANCE TRIPS) AND BLOWING CONTACTS
- MALFUNCTIONING IN ELECTRIC CIRCUIT ON RAPID OPENINGS AND LOSS OF COMMAND SIGNAL

BUT OVERALL CIRCUIT BREAKER PERFORMANCE ON SHORT-CIRCUIT SEEMS SATISFACTORY.

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOCIETY DES TRANSPORTS INTERCOMMUNAUX DE BRUXELLES (STIB) BRUSSELS, BELGIUM (LIGHT RAIL ONLY)		X		85	15		700V	500V			X	X		• CATENARY OVERHEAD STRUCTURES ARE CONNECTED TO RUNNING RAILS • GROUNDED RETURN CURRENT SYSTEM • 1 TO 1.5 KM LONG EACH ELECTRIFIED SYSTEM • 0.75 TO 3 MW CAPACITY OF TPS • 2 TPS/ELECTRIFIED SECTION • 14 YR. OLD EQUIPMENT • DOUBLE END FED SYSTEM • DOES NOT USE CONTACT RAIL DISCONNECT SWITCHES OR GAP BREAKER STATIONS • 4 TO 8 DC FEEDER BREAKERS PER TPS • 2000 AMPS TO 3500 AMPS DC FEEDER BREAKER RATING • 1 TO 2 MINUTE RUSH HOUR HEADWAY 5 MINUTE NON-RUSH HOUR HEADWAY • 1 CAR/TRAIN • 4, 6, 8 MOTORS/CAR • I_{ST} = 500A, 800A, 1200 AMPS • CAR MFRS. - BN-ACEC • CONTROL - PCC

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-59 of B-111
By N. S. SAGAR Date
Chkd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																	COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN																IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SH	CS					Y	N	Y	N	TPS	GBS	F	TF	SH	CS				Y	N	Y	N	
STIB BRUSSELS, BELGIUM (LIGHT RAIL ONLY)	NOT PROVIDED				← DATA NOT PROVIDED →									•BREAKERS •FUSES •DIFFERENTIA RELAYS •VISUAL INSPECTION ← NO OTHER DATA OR INFORMATION PROVIDED →		X		X		← DATA NOT PROVIDED →							•ADJUSTABLE TRIP HSCB WITH di/dt RELAYS ← NO OTHER DATA OR INFORMATION PROVIDED →		← DATA NOT PROVIDED →				PLAN TO INSTALL LCFD DEVICE IN TRAMWAY NETWORK ON EXPERIMENTAL BASIS. MAY SHARE THEIR EXPERIENCE WITH US THEN.
								D	OTHER													D	OTHER										

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-60 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MAATSCHAPPIJ VOOR HET INTERCOMMUNAAL VERVOER TE ANTWERPEN (MIVA) ANTWERP BELGIUM		X TRAM)		7		93			600V		X	X		● GROUNDED CATENARY OVERHEAD STRUCTURES ● GROUNDED RETURN CURRENT SYSTEM ● 1 TO 4 KM LONG SECTIONS ● 3 MW CAPACITY OF TPS ● 8 YR. OLD EQUIPMENT ● 1 TPS PER ELECTRIFIED SECTION ● DOUBLE CENTER FED SYSTEM ● 8 DC FEEDER BREAKERS PER TPS ● USES CONTACT RAIL DISCONNECT SWITCHES ● 2 MINUTE RUSH HOUR HEADWAY ● 6 MINUTE NON-RUSH HOUR HEADWAY ● 1 CAR/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 240 AMPS I_{RUN} = 156 AMPS ● CAR MFR - SPOORWEGMATERIEEL EN METAAL CONSTRUCTIES ● CONTROL - DRUM RESISTANCE CONTROL AND ACCELERATOR

MAIN 1803

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-61 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE						
	EXP'D		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
MIVA ANTWERP BELGIUM	X ARCING FAULTS NOT EXPERIENCED		X		◄── * ──►									● FUSES NO OTHER DATA OR INFORMATION PROVIDED		X		X									● SYSTEM SUPER-IMPOSES FIXED HIGH FREQUENCY TO DETECT - MOBILE FREQUENCY.	NONE	◄── * ──►				● QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

MAIN
1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-68 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MAATSCHAPPIJ VOOR HET INTERCOMMUNAAL VERVOER GHENT BELGIUM		X URBAN TRAMWAY			100		720V	420V	600V		X	X		● OVERHEAD CATENARY STRUCTURES ARE UNGROUNDED ALSO NOT CONNECTED TO RUNNING RAILS ● 1.5 KM LONG EACH ELECTRIFIED SECTION ● 1 MW CAPACITY OF EACH TPS ● 1 TPS PER EACH ELECTRIFIED SECTION ● 2 DC FEEDER BREAKER PER TPS ● 1500 AMPS RATING OF EACH DC FEEDER BREAKER ● SINGLE AND DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES ● 3 TO 9 MINUTE RUSH HOUR HEADWAY 6 TO 9 MINUTE NON-RUSH HOUR HEADWAY ● 1 CAR/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 200 AMPS I_{RUN} = 250 AMPS ● CAR MFRS – BN ● CONTROL – PCC ELECTRONIC CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-23 of B-111
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE						
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SH	CS					Y	N	Y	N	TPS	GBS	F	TF	SH	CS				Y	N	Y	N	
MIVG GHENT BELGIUM	NOT RESPONDED			X	← * →									NO DATA OR INFORMATION PROVIDED		ARCING FAULTS NOT EXPERIENCED				← * →							NO DATA OR INFORMATION PROVIDED		← * →				* QUESTIONNAIRE PART II WAS NOT MAILED AND HENCE DATA IDENTIFIED BY * COULD NOT BE COMPLETED
								D	OTHER													D	OTHER										

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-6 of B-11
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOCIÉTÉ NATIONALE DES CHEMINS DE FER VICINAUX (S.N.C.V.) BRUSSELS BELGIUM	X	X		1	96	3	720V	420V			X	X		● OVERHEAD CATENARY STRUCTURES CONNECTED TO RUNNING RAIL ● UNGROUNDED RETURN CURRENT SYSTEM ● 2 TO 5 KM LONG ELECTRIFIED SECTIONS ● 2 TPS PER ELECTRIFIED SECTION ● 1.3 MW CAPACITY OF EACH TPS ● 1 TO 15 YEARS OLD EQUIPMENT ● 4 DC FEEDER BREAKERS PER TPS ● 2000 AMPS RATING OF EACH FEEDER BREAKER ● USES GAP BREAKER STATION ● 7 MINUTE RUSH HOUR HEADWAY 15 TO 60 MINUTE NON-RUSH HOUR HEADWAY ● 1 TO 3 CARS/TRAIN ● 2 TO 4 MOTORS/CAR ● I_{ST} VARIES BETWEEN 105 AMPS TO 730 AMPS I_{RUN} VARIES BETWEEN 57.4 AMPS TO 420 AMPS ● CAR MFRS - RECONSTRUCTION SNCV & BN - ACEC ● CONTROL - CAM AND CHOPPER CONTROL

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-5 of B-10
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
S.N.C.V. BRUSSELS BELGIUM	ARCING FAULTS NOT EXPERIENCED				← DATA NOT PROVIDED →									• NO DEVICE BEING USED		X	ARCING FAULTS NOT EXPERIENCED				← DATA NOT PROVIDED →							• LINE FAULT DETECTOR RELAY ON DI/DT PRINCIPLE	-	DATA NOT PROVIDED				
														← NO OTHER DATA OR INFORMATION PROVIDED →														NO OTHER DATA OR INFORMATION PROVIDED						
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-111
By N. S. SAGAR Date
Chd. Rev

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
C. A. METRO DE CARACAS (MC) CARACAS VENEZUELA	X			80	10	10	950V	450V			X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 1.5 KM LONG EACH ELECTRIFIED SECTION ● 3.5 TO 4 MW CAPACITY OF EACH TPS ● 1 YEAR OLD EQUIPMENT ● 2 TPS/EACH ELECTRIFIED SECTION ● DOUBLE END FED SYSTEM ● USES GAP BREAKER STATIONS ● 4 DC FEEDER BREAKER PER TPS 4 DC FEEDER BREAKER PER GBS ● 6000 AMP RATING OF EACH DC FEEDER BREAKER ● 1 1/2 MINUTE RUSH HOUR HEADWAY 3 MINUTE NON-RUSH HOUR HEADWAY ● 7 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 620 AMP I_{RUN} = 400 AMPS. ● CAR MFRS - CIMT - ALSTHOM ATLANTIC ● CONTROLS - CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-7 of B-10

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN																IN TRACTION POWER SYSTEM												AFFECTED				
	LOW CURRENT FAULT														DETAILS OF LCFD DEVICE		LCF										DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
NC CARACAS VENEZUELA	X		X		← * →									● OVER CURRENT RELAYS ● FUSES ← NO OTHER DATA OR INFORMATION PROVIDED →		X		X									● TIMED OVERLOAD RELAY MFR. BY GEC-UK MODEL 150-ITR-1 ● ITE-76T RELAY MFR BY GOULD-BROWN BOVERI	NONE	← * →				●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-11 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION														
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
AKTIESELSKABET OSLO SPORVEIER (OS) OSLO, NORWAY (FOR METRO ONLY)	X			30		70	900V	525V			X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 1.5 TO 2.0 KM LONG ELECTRIFIED SECTION ● 1.5 TO 6 MW CAPACITY OF TPS ● UP TO 18 YR. OLD EQUIPMENT ● 1 TPS PER ELECTRIFIED SECTION ● 2 TO 6 DC FEEDER BREAKERS PER TPS ● 6000 AMPS RATING OF EACH DATA DC FEEDER BREAKER ● DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAP BREAKER STATIONS ● 1½ MINUTE RUSH HOUR HEADWAY 3½ MINUTE NON-RUSH HOUR HEADWAY ● 2 TO 6 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} VARIES BETWEEN 550 AMPS AND 750 AMPS ● CAR MFRS. - STRØMMENS VERKSTED, NATIONAL ELEKTRO, AEG, NEBB ● CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chk'd Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
OS OSLO NORWAY (FOR METRO ONLY)	X		X		←— * —→									•FUSES NO OTHER DATA OR ←— INFORMATION —→ PROVIDED		X ARCING FAULTS WERE NOT EXPERIENCED		X		←— * —→							•dI/dt SYSTEM APPLIED NO OTHER DATA OR ←— INFORMATION —→ PROVIDED		←— * —→				•QUESTIONNAIRE PART II DID NOT GET COMPLETED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
AKTIESELSKABET OSLO SPORVEIER (OS) OSLO, NORWAY (FOR LIGHT RAIL ONLY)		X		67		33	720V	420V			X	X		• OVERHEAD CATENARY STRUCTURES CONNECTED TO RUNNING RAIL • UNGROUNDED RETURN CURRENT SYSTEM • 1.5 TO 2 KM LONG ELECTRIFIED SECTION • 1.5 MW CAPACITY OF EACH TPS • 1 TPS PER ELECTRIFIED SECTION • UP TO 50 YR. OLD EQUIPMENT • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAP BREAKER STATIONS • 2 TO 5 DC FEEDER BREAKERS PER TPS • 5 MINUTE RUSH HOUR HEADWAY 10 MINUTE NON-RUSH HOUR HEADWAY • 1 TO 2 CARS/TRAIN • 2 MOTORS/CAR • I_{ST} = 800 AMPS • CAR MFRS. - DUEWAG/STROMMENS VERKSTED, NE, AEC, NEBB • CONTROL - CHOPPER CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-[illegible] of B-11
By N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="30">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="15">IN TRACTION POWER SYSTEM</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2" rowspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2" rowspan="2">DETAILS OF LCFD DEVICE</th><th colspan="2" rowspan="2">AFFECTED</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNCTIONAL LOCATION</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>MFR. MODEL</th><th>MISC. DATA INFO.</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>CBS</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>MFR. MODEL</th><th>MISC. DATA INFO.</th><th>SIGNAL SYSTEM Y N</th><th>COMM. SYSTEM Y N</th></tr>
<tr><td>OS OSLO NORWAY (FOR LIGHT RAIL ONLY)</td><td colspan="4">NO RESPONSE</td><td colspan="9">←— * —→</td><td colspan="2">●AUTOMATIC OVERLOAD PROTECTOR IN CHOPPER DEVICE
←— NO OTHER DATA OR INFORMATION PROVIDED —→</td><td>X</td><td></td><td>X</td><td></td><td colspan="7">←— * —→</td><td colspan="2">●di/dt SYSTEM APPLIED
←— NO OTHER DATA OR INFORMATION PROVIDED —→</td><td colspan="2">←— * —→</td><td>●QUESTIONNAIRE PART II DID NOT GET COMPLETED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="3"></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td colspan="2"></td><td colspan="4">ARCING FAULTS WERE NOT EXPERIENCED</td><td colspan="2"></td><td>D</td><td colspan="3">OTHER</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
</table>

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-7 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MOSKOVSKY METROPOLITAN IMENI LENINA (MMIL) MOSCOW, U.S.S.R.	X			96	-	4	975V	550V			X		X	• UNGROUNDED RETURN CURRENT SYSTEM • 12 MVA CAPACITY OF EACH TPS • 15 YR. OLD EQUIPMENT • 10 TO 18 TPS/ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 4 DC FEEDER BREAKER PER TPS • 6300 AMP RATING OF EACH DC FEEDER BREAKER • 80 SECOND RUSH HOUR HEADWAY 180 SECOND NON-RUSH HOUR HEADWAY • 6 TO 8 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 125 AND 140 AMPS I_{RUN} VARIES BETWEEN 280 AMPS AND 350 AMPS • CAR MFR. - MYTISHCHI • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-25 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	Y	N	Y	N	
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS								
MMIL MOSCOW USSR	ARCING FAULTS NOT EXPERIENCED	X		X	← * →									●CIRCUIT BREAKERS ← NO OTHER DATA OR INFORMATION PROVIDED →		← * →											●SENSORS ●CIRCUIT BREAKERS oELECTRONIC PROTECTION ← NO OTHER DATA OR INFORMATION PROVIDED →		← * →				THE INFORMATION PROVIDED IN RESPONSE TO QUESTIONNAIRE PART II WAS NOT ENOUGH TO COMPLETE THE DATA IDENTIFIED BY AN *.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SISTEMA DE TRANSPORTE COLLECTIVO (STC) MEXICO, D.F. MEXICO	X			62	13	25	750V				X		X	• UNGROUNDED RETURN CURRENT SYSTEM • 3.2 KM LONG EACH ELECTRIFIED SECTION • 2.5 AND 4.0 MW CAPACITY OF EACH TPS • 3 TO 14 YR. OLD EQUIPMENT • 2, 3 AND 4 TPS/SECTION • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 1 DC FEEDER BREAKER PER TPS • 9 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 500A AND 660 AMPS I_{RUN} VARIES BETWEEN 360A AND 400 AMPS • CAR MFR. - CIMT&B/L, CIMT/ALSTHOM CNCF MEXICO, BOMBARDIER

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TH	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
STC MEXICO, D.F. MEXICO	X		X		← * →									•THERMO-MAGNETIC TYPE FUSES AND RELAYS •ELECTRONIC SYSTEMS ← NO OTHER DATA OR INFORMATION PROVIDED →		X		X		← * →							•LOW IMPEDANCE DETECTION SYSTEM MFRD. BY CERME DCC 78 MODEL 7901	RELAY INSTRUCTIONS IN SPANISH WERE ATTACHED AS APPENDIX TO THE QUESTIONNAIRE PART I	← * →				QUESTIONNAIRE PART.II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
BUDAPESTI KÖZLEKEDÉSI VÁLLALAT (BKV) BUDAPEST, HUNGARY (FOR HIGH SPEED STREET CAR/BUS ONLY)			X HIGH SPEED STREET CAR/ BUS	77		23	720V	400V			X	X		• GROUNDED OVERHEAD CATENARY STRUCTURES • INDIRECTLY GROUNDED RETURN CURRENT SYSTEM • 0.8 KM LONG EACH ELECTRIFIED SECTION • 2, 4 & 8 MW TPS CAPACITY • 10 TO 15 YR. OLD EQUIPMENT • 4 TO 15 TPS PER ELECTRIFIED SECTION • SINGLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 16 DC FEEDER BREAKERS PER TPS • 1000 AMPS TO 2600 AMPS RATED DC FEEDER BREAKERS • 3 TO 10 MIN. RUSH HOUR HEADWAY 12 TO 15 MIN. NON-RUSH HOUR HEADWAY } FOR STREETCAR • 2 TO 3 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 540 AMPS AND 680 AMPS I_{RUN} VARIES BETWEEN 390 AMPS AND 490 AMPS • CAR MFRS. - CSKB PRAHA, GANZ VILLAMOSSAGI MOVK AND GANZ UV • CONTROL - MANUAL, ELECTROMECHANICAL AND ELECTRONICS

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet E-27 of E-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
BKV BUDAPEST HUNGARY (FOR HIGH SPEED CAR/BUS ONLY)	X			X	← * →									NO OTHER DATA OR INFORMATION PROVIDED		X			X	← * →							CURRENT TIMED PROTECTION ORIGINATED BY BKV NO OTHER DATA OR INFORMATION PROVIDED		← * →				●QUESTIONNAIRE PART II WAS NOT COMPLETED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
BUDAPESTI KÖZLEKEDÉSI VÁLLALAT (BKV) BUDAPEST, HUNGARY (METRO - NORTH-SOUTH EAST-WEST ONLY)	X			86 (NORTH-SOUTH)		14	900V	500V					X	● UNGROUNDED RETURN CURRENT CIRCUIT ● 11.2 KM (NORTH-SOUTH) } LONG EACH ELECTRIFIED 10.5 KM (EAST-WEST) } SECTION ● 6.6 MW (NORTH-SOUTH) } CAPACITY OF EACH TPS 5 MW (EAST-WEST) } ● 7 YR. OLD EQUIPMENT (NORTH-SOUTH) 15 YR. OLD EQUIPMENT (EAST-WEST) ● DOUBLE END FED SYSTEM ● 10 TPS (NORTH-SOUTH) } PER ELECTRIFIED SECTION 7 TPS (EAST-WEST) } ● 4 DC FEEDER BREAKERS PER TPS ● 3000 AMPS RATING OF EACH DC FEEDER BREAKER ● 127 SEC. RUSH HOUR HEADWAY } (NORTH-SOUTH) 360 SEC. (MAX.) NON-RUSH HOUR HEADWAY } 127 SEC. RUSH HOUR HEADWAY } (NORTH-SOUTH) 420 SEC. NON-RUSH HOUR HEADWAY } ● 5 CARS/TRAIN ● 4 MOTORS/CAR ● 1_{ST} = 800 AMPS I_{RUN} = 360 AMPS (NORTH-SOUTH) = 320 AMPS (EAST-WEST) ● CAR MFR. - MASCHIENENFABRIK MITISCSI ● CONTROL - CAM CONTROL
				85 (EAST-WEST)		15	900V	500V					X	

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-72 of B-111
By N. S. SACAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE						
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
BKV BUDAPEST HUNGARY (METRO NORTH-SOUTH & EAST-WEST ONLY)	X			X	X					X		NONE GIVEN	●N-S LINE INSULATOR BODY WAS PULLING OVER. ONE OF 5-CAR TRAIN HAD PNEUMATIC BREAK INSTEAD OF ELECTRIC.	NO OTHER DATA OR INFORMATION PROVIDED		X		X		IN STATION OF E-W LINE		X		X		ARCING S/C IN TRACTION RECTIFIER UNIT WHICH PERSISTED FOR 50 SECONDS.	●di/dt RELAY MFRD. BY SIEMENS TYPE 3UB51 (NORTH-SOUTH) ●NONE FOR (EAST-WEST)	●NONE ●NONE	X			X	
																ARCING FAULTS NOT EXPERIENCED (NORTH-SOUTH)													N-S LINE				
																X			X										NOT REPORTED FOR E-W LINE				
																(EAST-WEST)																	
								D	OTHER													D	OTHER										
																						X	DAMAGED AND DESTROYED ONE TRACTION RECTIFIER UNIT COMPLETELY IN E-W LINE.										

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
GÖTEBORGS SPÅRVÄGAR (GS) GÖTEBORG, SWEDEN		X		2		98	830V	540V			X	X		• GROUNDED OVERHEAD CATENARY SUPPORT STRUCTURES • GROUNDED RETURN CURRENT SYSTEM • 57.4 MW CAPACITY OF TPS • 86.9 KM LONG ELECTRIFIED SECTIONS • UP TO 40 YR. OLD EQUIPMENT • 37 TPS OR APPROX. 1.5 MW/TPS • GENERALLY SINGLE END FED SYSTEM SOME PART DOUBLE END FED • USES GAP BREAKER STATIONS • 3 DC FEEDER BREAKERS/TPS • 2000 AMP RATING OF EACH DC FEEDER BREAKER • 1 & 10 MINUTE HEADWAY DURING BOTH RUSH HOUR AND NON-RUSH HOUR • UP TO 4 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} = 500 AMPS I_{RUN} = 300 AMPS • CAR MFRS. - HAGGLUND & SONER, ASJ-ASEA • CONTROL - CONTACTOR CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-17 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
GS GÖTEBORG SWEDEN	X		X	X	← NO DATA AVAILABLE →							LACK OF MAINTENANCE	CONTACTORS AND MOTORS	• MOTORS DIFF. RELAYS MFRD. BY HAGGLUND & SÖNER TYPE RBBL-1C • MOTORS MAX. CURRENT RELAYS (ONE PER MOTOR GROUP) MFRD. BY ASEA TYPE RBL50E • CONTACTOR BOXES-EXCESS HEAT DETECTORS MFRD. BY PREMO SECURITY OF SWEDEN	• COMPARES MOTOR CURRENTS SET @ MAX. DIFF. 115 AMPS • SET @ 400 AMP/GROUP • SET @ 105° MAX. SHORTS THE TWO ISOLATED CABLES	X			X	← NO DATA PROVIDED →				X			• THERMAL OVERLOAD PROTECTION MFRD. BY ASEA TYPE RVAA5.1	• $I_{FUNC.}$ = 1000A • THERMAL TIME CONSTANT T_B = 15 MIN. • OPERATES SATISFACTORILY		X		X	THE CITY ENERGY DEPT. OWNS & OPERATES 37 SUBSTATIONS FEEDING CATENARY NO-FAULT DATA IS AVAILABLE FROM THEM.
								D	OTHER													D	OTHER										
																						X	DELAY BETWEEN STATIONS										

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-60 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
BUDAPESTI KÖZLEKEDÉSI VÁLLALAT (BKV) BUDAPEST, HUNGARY (VOORTABAHN LINE COMMUTER ONLY)			X COMMUTER RAIL	5		96	1300V	900V			X	X		● OVERHEAD CATENARY STRUCTURES ARE CONNECTED TO RUNNING RAILS ● UNGROUNDED RETURN CURRENT SYSTEM ● 21.3 KM LONG ELECTRIFIED SECTION ● 6.4 MW CAPACITY OF EACH TPS ● 2 TO 70 YR. OLD EQUIPMENT ● 4 TPS PER ELECTRIFIED SECTION ● SINGLE END FED SYSTEM ● 4 DC FEEDER BREAKERS PER TPS ● 3000 AMPS RATED DC FEEDER BREAKER ● 4 MINUTE RUSH HOUR HEADWAY 8 MINUTE NON-RUSH HOUR HEADWAY ● 3 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 600 AMPS I_{RUN} = 200 AMPS ● CAR MFR. - KLEW/DDR ● CONTROL - SINGLE DRUM AUTOMATIC CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE 8) ¹

Job No. 3819-1 Sheet B-81 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT												DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
UKV (COMMUTER RAIL LINE ONLY)	X			X			AT GRADE	X				FIRE AT QUICK-BREAK SWITCH CON-NECTION POINT DUE TO CABLE S/C NOT PROTECTED BY FUSE.	CABLE TO CAR BODY SHORT.	TS6000 AEG MFRD. HIGH SPEED CIRCUIT BREAKER ●SELECTIVE OVERCURRENT BY MANUAL CONTROL ●PROTECTION WITH AUTO-MATIC OVERCURRENT CUT-OFF ●OVERCURRENT DEVICE MFRD BY KLEW/GDR TYPE RSL-4 2/CAR	STATIC & DYNAMIC OVERCURRENT PROTECTION ●LCFD DEVICE WAS NOT IN-STALLED WHEN CABLE TO CAR BODY FAULT OCCURRED. ●MOTOR CKT. S/C's ARE PRO-TECTED ADEQUATELY BY RATING 450A/1100V	X			X	IN STATION		X		X		DC GROUND CABLE OUTGOING FROM TPS CREATED ARCING FAULT AND DUE TO CHAIN EFFECT OTHER CABLES RAN PARALLEL ALSO FAILED.	SIEMENS 30B51 TYPE di/dt RELAY	NONE		X		X	LOST THE TPS OUT OF SERVICE DUE TO CABLE FAULTS AND RESULTED IN EXTENSIVE CABLE NETWORK AND SWITCHING DEVICE DAMAGE. NEXT TPS PROVIDED POWER IN THE MEANTIME.
								D	OTHER													D	OTHER										
								X	BETWEEN STATIONS AT GRADE													X	DAMAGED CABLE NETWORK SERIOUSLY										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
THE PORT AUTHORITY OF THE STATE OF NEW YORK (PATH) NEW YORK & NEW JERSEY JERSEY CITY, N.J. U.S.A.	X			50	3	47	680V	500V	650V		X		X	• UNGROUNDED RETURN CURRENT SYSTEM • 0.2 MILE (IN TUNNEL) AND 2 MILE (OUTDOORS) LONG EACH ELECTRIFIED SECTION • 4 TO 9 MW TPS CAPACITY • ±20 YR. OLD EQUIPMENT • 2 TO 4 TPS/ELECTRIFIED SECTIONS • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS GAS • 10 DC FEEDER BREAKERS PER TPS & 3 DC FEEDER BREAKERS PER GBS • 4000 AMPS RATING OF EACH DC FEEDER BREAKER • 3 MINUTE RUSH HOUR HEADWAY 10 MINUTE NON-RUSH HOUR HEADWAY • 4 TO 7 CARS/TRAIN (12 TO 28 YR. OLD CARS) • 4 MOTORS/CAR • I_{ST} = 425 AMPS/CAR I_{RUN} = 80 AMPS • CAR MFRS. - ST. LOUIS CAR CO., HAWKER SIDDEY • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-25 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT												DETAILS OF LCFD DEVICE			LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
PATH JERSEY CITY N.J. U.S.A.	X			X	←— * —→							GROUND FAULTS IN CABLES AND ON MOTOR	•TRACTION MOTORS •CABLES	•COLUMBIA COMPONENTS CO. INC. MFRD. GROUND FAULT & DYNAMIC BRAKE TRACTION MOTOR PROTECTION DEVICE •CKT. BKRS. •FUSES	•CONSISTS OF SATURABLE REACTOR WHICH SENSES A CURRENT INBALANCE IN THE TRACTION MOTORS IF MORE THAN PRESET ONE. (INFO. BASED ON A TELECON W/PATH) •REPORTED EXCELLENT PERFORMANCE ON THE CARS IT IS INSTALLED	X			X	←— * —→							G.E. CO. MFRD. MC-6 BREAKERS FOR INSTANTANEOUS SHUNT TRIP	NO OTHER STUDIES ARE UNDERWAY	←— * —→				THE DETAILS FOR ITEMS IDENTIFIED BY AN * WERE NOT REPORTED, HENCE COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet [illegible] of [illegible]
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY (MARTA) ATLANTA, GEORGIA, U.S.A.	X			30	35	35	900V	750V			X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 6 MW CAPACITY OF EACH TPS ● 7 YR. OLD EQUIPMENT ● 2 TPS PER ELECTRIFIED SECTION ● DOUBLE END FED SYSTEM ● 2000 AMPS & 2500 AMPS RATINGS OF DC FEEDER BREAKER ● USES GAP BREAKER STATIONS ● 5 DC FEEDER BREAKERS PER TPS 3 DC FEEDER BREAKERS PER GBS ● 6 MIN. BOTH RUSH HOUR AND NON-RUSH HOUR HEADWAY ● 6 CARS/TRAIN ● 4 MOTORS/CAR ● I_{ST} = 640 AMPS I_{RUN} = 230 AMPS ● CAR MFR. - FRANCO BELGE ● CONTROL - CHOPPER CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet 82 of B-III
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
MARTA ATLANTA GA, U.S.A.	X		NOT RESPONDED TO		← * →									CIRCUIT BREAKERS		X		NOT RESPONDED TO		← * →							JAMES A. BIDDLE GROUND DETECTOR DEVICE		← * →				QUESTIONNAIRE PART II WAS NOT MAILED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
	ARCING FAULTS ← NOT → EXPERIENCED													← NO OTHER DATA OR INFORMATION PROVIDED →		ARCING FAULTS ← NOT → EXPERIENCED											← NO OTHER DATA OR INFORMATION PROVIDED →						
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B.26 of B-111
By N. S. SAGAR Date
Chd. Rev.

	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
TRANSIT SYSTEM	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
STRATHCLYDE PASSENGER TRANSPORT EXECUTIVE (SPTE) GLASGOW, SCOTLAND	X			100			645V	440V			X		X	• GROUNDED RETURN CURRENT SYSTEM • 3.1 TO 3.9 KM LONG EACH ELECTRIFIED SECTION • 2 MW CAPACITY OF EACH TPS • 30 YR. OLD EQUIPMENT • 3 TPS PER ELECTRIFIED SECTION • CENTER FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 2 DC FEEDER BREAKERS PER TPS • 1600 AMPS CAPACITY OF EACH DC FEEDER BREAKER • 4 MINUTE RUSH HOUR HEADWAY 6 TO 8 MINUTE NON-RUSH HOUR HEADWAY • 2 TO 3 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} = 258 ±8 AMPS I_{RUN} = 100 AMPS • CAR MFR. - METRO CAMMELL LTD. • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-89 of B-111

By N. S. SAGAR Date

Chd. Rev.

	LOW CURRENT FAULT DATA																																
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
TRANSIT SYSTEM	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED SIGNAL SYSTEM		COMM. SYSTEM		COMMENTS AND/OR REMARKS
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
SPTE GLASGOW SCOTLAND	X		X		← * →									FUSES		NOT RESPONDED TO				← * →							GEC & ENGLISH ELECTRIC AIR BREAK HSCB WORKING ON OVERCURRENT TRIP PRINCIPLE		← * →				*QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
	ARCING FAULTS ← NOT → EXPERIENCED													← NO OTHER DATA OR INFORMATION PROVIDED →		ARCING FAULTS ← NOT → EXPERIENCED											← NO OTHER DATA OR INFORMATION PROVIDED →						
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-22 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
LONDON TRANSPORT EXECUTIVE (LTE) LONDON, ENGLAND	X			30		8	700V	550V			X		X	• UNGROUNDED RETURN CURRENT SYSTEM • .3 TO 9 MW CAPACITY OF TPS • UP TO 40 YR. OLD EQUIPMENT • AVERAGE 5 TPS PER ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES • 4 DC FEEDER BREAKERS PER TPS • 4000 AMPS RATING OF EACH TPS • 1½ MIN. RUSH HOUR HEADWAY UP TO 20 MIN. NON-RUSH HOUR HEADWAY • 2 TO 4 CARS (VARIES)/TRAIN • 2 TO 4 MOTORS (VARIES)/CAR • I_{ST} VARIES BETWEEN 453 AMPS IN SERIES 906 AMPS IN PARALLEL AND 370 AMPS IN SERIES 740 AMPS IN PARALLEL I_{RUN} VARIES BETWEEN 283 AMPS & 370 AMPS • CAR MFR. - METRO CAMMELL, CRAVENS • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-21 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
LTE LONDON ENGLAND	X		X		*									•NONE	•NONE	X		X		*							•TIMED OVERCURRENT TRIP (TOC) •UNBALANCED CURRENT PROTECTION (UCP)	•TOC SET TO DETECT MINIMUM SHORT CKT. VALUE IN SECTION, BUT LIMITED TO ALLOW I_{ST} IN EXCESS FOR NORMAL SERVICE. •UCP DETECTS LOW VALUE FAULTS SUCH AS WOULD CIRCULATE IF TWO TRAINS WITH OPP. POLARITY FAULTS WERE ON DIFFERENT TRACKS OF THE SAME SECTION. •BRIEF WRITEUP FOR TOC & UCP PROVIDED.	*				•QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-9 of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
SOCIETE LYONNAISE DE TRANSPORTS EN COMMUN (TCL) LYON, FRANCE	X			100			750V				X		X	• UNGROUNDED RETURN CURRENT SYSTEM • 3 KM LONG EACH ELECTRIFIED SECTION • 2.75 MW CAPACITY OF EACH TPS • 6 YR. OLD EQUIPMENT • 1 TPS/ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SWITCHES AND GBS • 2 DC FEEDER BREAKERS PER TPS • 7000 AMPS RATING OF EACH DC FEEDER BREAKER • 2'-48" RUSH HOUR HEADWAY 10'-30" NON-RUSH HOUR HEADWAY • 3 TO 4 CARS/TRAIN • 2 MOTORS/CAR • I_{ST} = 650 AMPS I_{RUN} = 350 AMPS • CAR MFR. - ALSTHOM • CONTROL - CHOPPER CONTROL

MAIN
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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-93 of B-111
By N. S. SAGAR Date
Chd. Rev.

	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
TRANSIT SYSTEM	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
TCL LYON FRANCE	X		X		*									•CIRCUIT BREAKERS •FUSES NO OTHER DATA OR INFORMATION PROVIDED		X		X		*							•DDL RELAYS MFRD. BY BBC - SECHERON NO OTHER DATA OR INFORMATION PROVIDED		*				•QUESTIONNAIRE PART II WAS FORWARDED BY TCL TO ITS MEMBER COMPANY TRANSTEC WHICH DID NOT REPLY, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D		OTHER												D		OTHER									

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet E-9 of E-11

By N. S. SACAR Date

Chd. Rev.

	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
TRANSIT SYSTEM	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
METROPOLITANO DE LISBOA, E.P. (CML) LISBON, PORTUGAL	X			100			900V	525V			X		X	• UNDERGROUND RETURN CURRENT SYSTEM (4 RUNNING RAILS ARE IN PARALLEL WITH 2-500 MCM COPPER CABLES) • 2.75 KM LONG EACH ELECTRIFIED SECTION • 3 TO 6 MW CAPACITY OF TPS • 2 TPS/ELECTRIFIED SECTION • UP TO 24 YR. OLD EQUIPMENT • DOUBLE END FED SYSTEM • USES GBS • 2 DC FEEDER BREAKERS PER TPS & 2 DC FEEDER BREAKERS PER GBS • 6400 AMPS RATING OF EACH DC FEEDER BREAKER • 2'-35" RUSH HOUR HEADWAY 6'-0" NON-RUSH HOUR HEADWAY • 4 CARS/TRAIN • 2 TO 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 330 AMPS & 350 AMPS/MOTOR I_{RUN} VARIES BETWEEN 255 AMPS & 266 AMPS/MOTOR • CAR MFR. - LHB/SOREFAME/SIEMENS ALSTHOM/EFACEC • CONTROL - CAM CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-25 of B-111

By N. S. SAGAR Date

Ckd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION			EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO							
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS			MFR. MODEL	MISC. DATA INFO.	Y	N	Y	N	TPS	GBS	F	TF	SM	CS		MFR. MODEL	MISC. DATA INFO.	Y	N	Y	N	
CML LISBON PORTUGAL	X			X	*									•DIFFERENTIAL PROTECTION •ΔI PROTECTION		X			X	*							•di/dt DEVICES IN NEW SUBSTATION RECENTLY IN SERVICE		*				•QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
														NO OTHER DATA OR INFORMATION PROVIDED													NO OTHER DATA OR INFORMATION PROVIDED						
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
STADTWERKE MÜNCHEN - WERKBEREICH TECHNIK VERKEHRSBETRIEBE (MVG) MÜNCHEN FEDERAL REPUBLIC OF GERMANY (METRO ONLY)	X			8		92		750V			X		X	● UNGROUNDED RETURN CURRENT SYSTEM ● 2 TO 3 KM LONG EACH ELECTRIFIED SECTION ● 2.5 MW CAPACITY OF EACH TPS ● UP TO 16 YR. OLD EQUIPMENT ● DOUBLE END FED SYSTEM ● USES CONTACT RAIL DISCONNECT SWITCHES AS WELL AS CBS ● 4 DC FEEDER BREAKER/TPS ● 4000-6000 AMPS RATING OF DC FEEDER BREAKER ● 2½ to 5 MIN. RUSH HOUR HEADWAY 5 TO 10 MIN. NON-RUSH HOUR HEADWAY ● 2 TO 6 CARS/TRAIN ● 2 MOTORS/CAR ● I_{ST} VARIES BETWEEN 320 AMPS & 725 AMPS ● CAR MFRS. - MBB ● CONTROL - CAM AND MANUAL CURRENT CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-97 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SH	CS					Y	N	Y	N	TPS	GBS	F	TF	SH	CS				Y	N	Y	N	
MVG MÜNCHEN FEDERAL REPUBLIC OF GERMANY (METRO ONLY)	X IN OTHER TYPE OF CAR ARCING FAULTS NOT EXPERIENCED		X		← * →									●MINIATURE CONTROL oSCREW CONTROL oOVERCURRENT PROTECTION ← NO OTHER DATA OR INFORMATION PROVIDED →		X			X	← * →							●ADJUSTABLE dI/dt DEVICE IN THE FEEDER BREAKER TO DIFFERENTIATE NEARBY & FARAWAY FAULTS	●LAB METHODS FOR TESTING INDIVIDUAL FEEDER BREAKER IS BEING DEVELOPED IN RECTIFIER STATIONS	← * →				●QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-[illegible] of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	MISCELLANEOUS SYSTEM DATA
STADWERKE MÜNCHEN - WERKBEREICH TECHNIK VERKEHRSBETRIEBE (MVG) MÜNCHEN FEDERAL REPUBLIC OF GERMANY (LIGHT RAIL ONLY)		X		100				650V			X	X		• UNGROUNDED OVERHEAD CATENARY STRUCTURES • GROUNDED RETURN CURRENT SYSTEM • UP TO 3 KM LONG EACH ELECTRIFIED SECTION • 16 MW TPS CAPACITY • 15 TO 40 YR. OLD EQUIPMENT • 1 TPS ELECTRIFIED SECTION • SINGLE END FED SYSTEM • USES CONTACT RAIL DISCONNECT SYSTEM • 4 TO 12 DC FEEDER BREAKERS PER TPS • 2500 AMPS RATING OF EACH DC FEEDER BREAKER • 2½ - 3 MIN. RUSH HOUR HEADWAY 5 - 15 MIN. NON-RUSH HOUR HEADWAY • 2 CARS/TRAIN • 2 OR 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 384 AMPS & 475 AMPS • CAR MFR. - RATHGEBER • CONTROL - CAM CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-22 of B-111

By N. S. SAGAR Date

Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
MVG MÜNCHEN FEDERAL REPUBLIC OF GERMANY (LIGHT RAIL ONLY)	X		X		*									• MINIATURE CIRCUIT BREAKER • SCREW CONTROL • OVERCURRENT PROTECTION NO OTHER DATA OR INFORMATION PROVIDED		X		X		*							• DEVICE (CIRCUIT BREAKER) TRIPS AT THE FAULT IN THE SECTION ONLY WHEN THE TOTAL SECTION RESISTANCE IS ABOVE 1.2 Ω. NO OTHER DATA OR INFORMATION PROVIDED		*				• QUESTIONNAIRE PART II NOT RETURNED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-102 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
METROPOLITAN TRANSIT DEVELOPMENT BOARD (MTDB) SAN DIEGO, CALIFORNIA U.S.A.		X				100	750V	450V			X	X		• GROUNDED OVERHEAD CATENARY STRUCTURES • UNGROUNDED RETURN CURRENT SYSTEM • 1 MILE LONG EACH ELECTRIFIED SECTION • 1 MW CAPACITY OF EACH TPS • 5 YR. OLD EQUIPMENT OR LESS • APPROXIMATELY 1 TPS PER ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • 2 DC FEEDER BREAKERS PER TPS • 2500 AMPS RATING OF DC FEEDER BREAKER • 15 MIN. RUSH HOUR HEADWAY 15-30-60 MIN. NON-RUSH HOUR HEADWAY • 1 TO 4 CARS/TRAIN • 2 MOTORS/CAR • I_{ST} = 250 AMPS I_{RUN} = 180 AMPS • CAR MFR. - SIEMENS/DUEWAG • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-101 of B-111
By N. S. SAGAR Date
Chk. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM																	
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		AFFECTED				
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.	SIGNAL SYSTEM		COMM. SYSTEM		
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	CBS	F	TF	SM	CS				Y	N	Y	N	
MTDB SAN DIEGO CALIFORNIA U.S.A.	RESPONDED WITH N/A AND ARCING FAULTS NOT EXPERIENCED				← * →									•OVERCURRENT RELAY ← NO OTHER DATA OR INFORMATION PROVIDED →		NOT RESPONDED TO				← * →							•RATE-OF-RISE RELAYS MFRD. BY ITE	NONE	← * →				•QUESTIONNAIRE PART II WAS NOT SENT TO MTDB HENCE THE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED.
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-11 of B-111

By N. S. SAGAR Date

Chd. Rev

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
THE CITY OF EDMONTON EDMONTON, ALBERTA CANADA		X	X TROL-LEY BUS	←— * —→					600V		X	(		*THIS AND OTHER SYSTEM DATA WAS NOT PROVIDED. • 3 CARS/TRAIN

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-103 of B-111
By N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="32">LOW CURRENT FAULT DATA</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="15">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th><th colspan="4" rowspan="2">AFFECTED</th></tr>
<tr><th colspan="13">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNCTIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>GBS</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td rowspan="5">THE CITY OF EDMONTON ALBERTA CANADA</td><td></td><td>X</td><td></td><td>X</td><td colspan="9" rowspan="4">*</td><td rowspan="2">●INSTANTANEOUS &
●TIMED OVERCURRENT RELAYS.</td><td rowspan="2"></td><td colspan="11" rowspan="4">*</td><td rowspan="4">●RATE-OF-RISE RELAYS
●MONITORS RAIL TO GROUND VOLTAGE GIVING ALARM AT VALUE OF MORE THAN 450 VOLTS</td><td rowspan="4">●REDESIGNED FEEDER LENGTHS FOR TROLLEY BUS NETWORK</td><td colspan="4" rowspan="4">*</td><td rowspan="5">●QUESTIONNAIRE PART II WAS NOT MAILED.
●DATA IDENTIFIED WITH AN * WAS NOT PROVIDED
●RESPONSE FROM THE CITY OF EDMONTON WAS A REFERRAL FROM CANADIAN URBAN TRANSIT ASSOCIATION (CUTA)</td></tr>
<tr><td colspan="4">(FOR LIGHT RAIL)</td></tr>
<tr><td>X</td><td></td><td>X</td><td>X</td><td colspan="2" rowspan="2">NO OTHER DATA OR INFORMATION PROVIDED</td></tr>
<tr><td colspan="4">(FOR TROLLEY BUS NETWORK)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-10-1 of B-11
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
THE CITY OF CALGARY ELECTRIC SYSTEM ALBERTA, CANADA		X		←	*	→			600V		X	X		• *THIS AND OTHER SYSTEM DATA WAS NOT PROVIDED. • DOUBLE END FED SYSTEM

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-105 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
THE CITY OF CALGARY ELECTRIC SYSTEM ALBERTA, CANADA		X		X	← * →									•CKT. BKRS. ON-BOARD CARS OFFERED BY SIEMENS	← NO OTHER DATA OR INFORMATION PROVIDED →	X		X		← * →							•OVERCURRENT RELAYS odi/dt RELAYS (IT SEEMS THEY HAVE SIEMENS MFRD. RELAY DEVICE •MONITORING RAIL VOLTAGE TO GROUND GIVING ALARM FOR GREATER THAN 30V ← NO OTHER DATA OR INFORMATION PROVIDED →		← * →				•QUESTIONNAIRE PART II WAS NOT MAILED •DATA IDENTIFIED WITH AN * WAS NOT PROVIDED •RESPONSE FROM THE CITY OF CALGARY WAS A REFERRAL FROM CANADIAN URBAN TRANSIT ASSOCIATION (CUTA)
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1
Sheet B-105 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
JAPANESE NATIONAL RAILWAYS (JNR) TOKYO, JAPAN	X		X COM- MUTER	←					*				→	*THIS AND OTHER SYSTEM DATA WAS NOT PROVIDED.

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-107 of B-111
By N. S. SAGAR Date
Chkd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
JNR TOKYO JAPAN	← * →															X		X		← * →							•FAULT SELECTIVE DEVICE FOR D.C. FEEDER MANUFACTURED BY TSUDA ELECTRIC METER CO. OF JAPAN	•WORKS ON Δ I PRINCIPLE •ADDITIONAL FAULT ANALYSIS METHOD EXPLANATION WAS PROVIDED	← * →				•QUESTIONNAIRE PART II WAS NOT MAILED •DATA IDENTIFIED BY AN * WAS NOT PROVIDED •RESPONSE FROM JNR WAS A REFERRAL FROM JAPANESE RAILWAY ENGINEERS ASSOCIATION
								D	OTHER													D	OTHER										

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-10 of B-10
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													
	TYPE			MAJORITY			VOLTAGE					DIST. BY		MISCELLANEOUS SYSTEM DATA
	METRO	LIGHT RAIL	OTHER	UC %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
NEW ZEALAND RAILWAY CORPORATION WELLINGTON, NEW ZEALAND			X COMMUTER RAIL	NOT RESPONDED TO			1800V	1100V			X	X		• CATENARY OVERHEAD STRUCTURES ARE CONNECTED TO RUNNING RAILS • GROUNDED RETURN CURRENT SYSTEM • 6 TO 15 KM LONG ELECTRIFIED SECTIONS • 1.8 TO 4.5 MW CAPACITY OF TPS • UP TO 30 YR. OLD EQUIPMENT • 4 TO 6 TPS PER ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • USES GAP BREAKER STATIONS • 2 TO 4 DC FEEDER BREAKERS/TPS • 4 DC FEEDER BREAKERS/GBS • 4000 AMPS RATING OF DC FEEDER BREAKER • 6 TO 7 MIN. RUSH HOUR HEADWAY 1 HOUR NON-RUSH HOUR HEADWAY • 2 TO 8 CARS/TRAIN • I_{ST} VARIES BETWEEN 250 AMPS AND 700 AMPS • CAR MFR. - GANZ MAVAG, ENGLISH ELECTRIC CORP. • CONTROL - CAM CONTROL

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B-109 of B-111
By N. S. SAGAR Date
Chd. Rev.

TRANSIT SYSTEM	LOW CURRENT FAULT DATA																																COMMENTS AND/OR REMARKS
	ON-BOARD TRAIN															IN TRACTION POWER SYSTEM													AFFECTED				
	LOW CURRENT FAULT													DETAILS OF LCFD DEVICE		LCF											DETAILS OF LCFD DEVICE		SIGNAL SYSTEM		COMM. SYSTEM		
	EXP'D?		D/S?		OCCURRED IN/AT			RESULTED IN				CAUSED DUE TO	FUNCTIONAL LOCATION	MFR. MODEL	MISC. DATA INFO.	EXP'D?		D/S?		HOW FAR OCCURRED FROM		RESULTED IN				CAUSED DUE TO	MFR. MODEL	MISC. DATA INFO.					
	Y	N	Y	N	TU	ST	OTHER	F	TF	SM	CS					Y	N	Y	N	TPS	GBS	F	TF	SM	CS				Y	N	Y	N	
NEW ZEALAND RAILWAY CORPORATION WELLINGTON NEW ZEALAND	X			X	*							LCF IN HEATER CIRCUIT (GROUNDED END)	SERIES CONNECTED HEATER CHAIN GROUNDED END	NO OTHER DATA OR INFORMATION PROVIDED		X		NOT RESPONDED TO		*							NO OTHER DATA OR INFORMATION PROVIDED		*				•QUESTIONNAIRE PART II WAS NOT MAILED, HENCE DATA IDENTIFIED BY AN * COULD NOT BE COMPLETED
																ARCING FAULTS NOT EXPERIENCED																	
								D	OTHER													D	OTHER										

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT 43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE A)

Job No. 3819-1 Sheet B-110 of B-111

By N. S. SAGAR Date

Chkd. Rev.

TRANSIT SYSTEM	BRIEF SYSTEM DESCRIPTION													MISCELLANEOUS SYSTEM DATA
	TYPE			MAJORITY			VOLTAGE					DIST. BY		
	METRO	LIGHT RAIL	OTHER	UG %	E %	SS %	MAX.	MIN.	NOM.	AC	DC	C	T	
MASS TRANSIT RAILWAY CORPORATION (MTRC) HONG KONG	X			77	20	3			1500V		X	X		• GROUNDED CATENARY OVERHEAD STRUCTURES • UNGROUNDED RETURN CURRENT SYSTEM • 2.5 KM LONG ELECTRIFIED SECTION • 8 MW CAPACITY OF TPS • 2 TO 4 YR. OLD EQUIPMENT • 2 TPS PER ELECTRIFIED SECTION • DOUBLE END FED SYSTEM • 4 DC FEEDER BREAKERS PER TPS • 3000 AMPS RATING OF DC FEEDER BREAKER • 2 MIN. RUSH HOUR HEADWAY 5 TO 10 MIN. NON-RUSH HOUR HEADWAY • 2 TO 4 CARS/TRAIN • 4 MOTORS/CAR • I_{ST} VARIES BETWEEN 400 AMPS AND 450 AMPS I_{RUN} VARIES BETWEEN 180 AMPS AND 220 AMPS • CAR MFR. - METRO-CAMMELL • CONTROL - CAM, CHOPPER & OTHER CONTROL

MAIN 1893

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT - 43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES FROM TRANSIT SYSTEMS (SIDE B)

Job No. 3819-1 Sheet B11 of B-11
By N. S. SAGAR Date
Chd. Rev.

<table>
<tr><th rowspan="5">TRANSIT SYSTEM</th><th colspan="29">LOW CURRENT FAULT DATA</th><th colspan="4" rowspan="3">AFFECTED</th><th rowspan="5">COMMENTS AND/OR REMARKS</th></tr>
<tr><th colspan="16">ON-BOARD TRAIN</th><th colspan="13">IN TRACTION POWER SYSTEM</th></tr>
<tr><th colspan="14">LOW CURRENT FAULT</th><th colspan="2">DETAILS OF LCFD DEVICE</th><th colspan="11">LCF</th><th colspan="2">DETAILS OF LCFD DEVICE</th></tr>
<tr><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="3">OCCURRED IN/AT</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">FUNC-TIONAL LOCATION</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th rowspan="2">MFR. MODEL</th><th colspan="2">EXP'D?</th><th colspan="2">D/S?</th><th colspan="2">HOW FAR OCCURRED FROM</th><th colspan="4">RESULTED IN</th><th rowspan="2">CAUSED DUE TO</th><th rowspan="2">MFR. MODEL</th><th rowspan="2">MISC. DATA INFO.</th><th colspan="2">SIGNAL SYSTEM</th><th colspan="2">COMM. SYSTEM</th></tr>
<tr><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TU</th><th>ST</th><th>OTHER</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th><th>TPS</th><th>GBS</th><th>F</th><th>TF</th><th>SH</th><th>CS</th><th>Y</th><th>N</th><th>Y</th><th>N</th></tr>
<tr><td>MTRC
HONG KONG</td><td>X</td><td></td><td>X</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td>POWER FAULT</td><td>AUXIL-IARY SYSTEMS</td><td>●MOTORING OVERLOAD RELAY (OLM) MFR.-GEC ENGLAND TYPE 50TR16B1
●BRAKING OVERLOAD RELAY (OLB) MFR.-GEC ENGLAND TYPE 50TR14B1
●MA SET OVERLOAD RELAY (MAOR) MFR. -GEC ENGLAND TYPE 31TR16B2</td><td>●OLM RATING RESET COIL RESISTANCE 472.6 Ω MINIMUM OPERATING VOLTAGE 50V RANGE- 800 TO 1600A
●OLB RATING 472.6 Ω 50V, 400 TO 800A
●MAOR RATING 60-80-100A D.C. CURRENT SETTING OF TRIP COIL 80A D.C.</td><td></td><td>X</td><td></td><td></td><td>X</td><td>1 KM</td><td></td><td></td><td></td><td></td><td></td><td>ARCING FAULT IN STATIONS ABOVE GRADE</td><td>●UNDER VOLTAGE DETECTION SYSTEM WITH TIME DELAY OVERCURRENT SHUNT TRIP MFRD. BY GEC-ENGLAND MODEL # VAG12</td><td>SAME AS PILOT WIRE VOLTAGE SENSING METHOD</td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>D</td><td colspan="3">OTHER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td colspan="3">DELAY BETWEEN STATIONS NOT IN TUNNEL</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">NO UNSAFE CONDI-TIONS RESULTED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

APPENDIX C

SUMMARY OF RESPONSES FROM MANUFACTURERS AND SUPPLIERS

Negative responses were received from:

- Union Switch & Signal, Pennsylvania, U.S.A.
- Sasib SpA, Italy
- AVM Systems Inc., Texas, U.S.A.
- Duewag AG, Federal Republic of Germany
- Valmet Oy, Finland
- Indian Railway Integral Coach Factory, India

Referrals were provided by SAE (India) Ltd.—referred to Research Design & Standards Organization, Ministry of Railways, India, which also remained as non-respondee.

Positive responses were received as noted on the remaining pages of this appendix.

MAIN

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-2 of C-9
By N. Sagar Date
Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
ASEA INC., RELAY & CONTROL DIV. YONKERS, NY 10701	X	X	INDUSTRY APPLICATIONS AS WELL	●PILOT WIRE DIFFERENTIAL RELAYS WITH BASIC UNITS, SUMMATION CT, OUTPUT RELAY, PILOT WIRE SUPERVISION ON EQUIPMENT AND SENDING END UNIT & RECEIVING END UNIT ●TYPE RADHL (BASIC VERSION) + RXME OR RXMS OUTPUT RELAY. +RXIL24 FAULT DETECTORS ●TYPE RXEL FOR DC APPLICATIONS	VOLTAGE LEVEL COMPARISON TYPE DC & AC MONITORING SYSTEM. ●RADHL FOR AC ●RXEL FOR DC	RELAYS ACCESS & PACKAGE ASSEMBLY COSTS ≃$3500 WITH ADD'L. COSTS FOR PILOT WIRES, INSTALLATION, TAXES & FREIGHT.		X	NEEDED CUSTOM MADE PACKAGE BASED ON THE SYSTEM	MAXIMUM 26 WEEKS DELIVERY	OFFERS HIGHLY SENSITIVE INSTANTANEOUS AC & DC OVER-CURRENT RELAY TYPE RXIK 1	●OVER-CURRENT ON GROUNDING OR ARCING RANGE 0.5 mA to 2 mA OPERATE VALUE. ●ARC MONITOR TYPE TVOA NORMALLY OFFERED FOR WITHIN THE GEAR INSTALLATION CAN BE USED TO DETECT ARCING FOR TRACTION MOTORS.	●$221 PER RELAY w/12 WKS. DELIVERY ●$500/UNIT OR LESS ●$3500/MILE APPROX. FOR PILOT CABLE (MAT. & LABOR) IN THE EXISTING THROUGH	← NO OTHER DATA PROVIDED →				●RESPECTIVE BROCHURE & BRIEF TECHNICAL DATA IS PROVIDED. ●STATED THEY HAVE FURNISHED PILOT WIRING SCHEME TO MTA-N.Y., NJDOT, CONRAIL, AUSTRALIA AND AUSTRIAN SYSTEMS. ●COST LOWEST IF TO BE INSTALLED IN NEW PLANNED SYSTEM. FOR THE EXISTING SYSTEM IF NO SPACE IS AVAILABLE. FOR SHIELDED CABLE IN RIGHT-OF-WAY, FIBER-OPTIC CABLE CAN BE INSTALLED ON EXISTING OR CATENARY STRUCTURE, AT ADDITIONAL COST.

MAIN

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-3 of C-9

By N. Sagar Date

Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
BROWN BOVERI ●BBC BROWN BOVERI CANADA LTD. POINTE CLAIRE, QUEBEC, CANADA ●BBC-SECHERON LTD., GENEVA, SWITZERLAND	X	X	UTILITIES & INDUSTRY PROTECTION SYSTEM	●DDL ●PCC RELAYS MODEL -E-26 -E-46 -EN- -BCA -ACA-11 -PCC-67	di/dt & Δi PRINCIPLE DETECTS, MEASURES & ANALYZES THE FDR, CURRENT & ITS INCREMENT, INDEPENDENT OF FAULT TIME CONSTANTS	CANADIAN $5000 FOR ACA-11 PRICES FOR OTHER MODELS WERE NOT PROVIDED	X		EASILY ADAPTABLE TO ANY EXISTING OR NEW SYSTEM. GETS CONNECTED AT EXISTING SHUNT OF DC BREAKER.	●FOR DDL ACA-11 A DETAILED TECHNICAL DATA IS PROVIDED TO FACILITATE THOROUGH ANALYSIS. ●IN-DEPTH FAULT CLEARING INVESTIGATION WAS UNDERTAKEN BY TTC AND MONTREAL METROS SUCCESSFULLY FOR DDL-ACA-11 & PCC-67 MODELS. oLONG LIST OF WORLDWIDE CUSTOMERS IS PROVIDED.	HIGH SPEED CKT. BKR TYPES UR12 AND UR-6 TO BE MOUNTED ON-BOARD CARS.	●CURRENT INTERRUPTION DEPENDS ON di/dt or TIME CONSTANT OF THE PROTECTED CIRCUIT. ●PERFORMS DIRECT AS WELL AS INDIRECT TRIPPING WITH LOW & HIGH SPEED RELEASE.	NOT PROVIDED	← NONE STATED →			A DETAILED BROCHURE IS PROVIDED TO FACILITATE A THOROUGH ANALYSIS.	● BASED ON TTC TESTING WITNESSED, THE DDL-ACA-11 RELAYS DO CLEAR BOLTED, ARCING AND SOME HIGH RESISTANCE FAULTS IN VARIOUS FAULT CONDITIONS NEAR TPS OR ON THE R-O-W MID-POINTS OF TPS. ● BASED ON WORLDWIDE SURVEY OF TRANSIT SYSTEMS FOR THIS PROJECT, IT APPEARS MAJORITY OF SYSTEMS USE BBC-SECHERON DDL-ACA-11 RELAYS.

MAIN

Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-4 of C-9
By N. Sagar Date
Chk. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
COLUMBIA COMPONENTS CO. INC. NEW JERSEY, U.S.A.		X		← NO OTHER DATA OR INFORMATION PROVIDED →							•GROUND FAULT & DYNAMIC TRACTION MOTOR PROTECTION SYSTEM •HEATER FAULT DETECTION SYSTEM	•SATURABLE REACTORS SENSE THE CURRENT UNBALANCE IN TRACTION MOTOR LEADS. •WORKS ON HEATER SUPPLY VOLTAGE FLUCTUATIONS, CALCULATES THE PROPER CURRENT FOR HEATER STRING & COMPARES IT WITH ACTUAL CURRENT. THE DIFFERENCE BETWEEN THESE TWO CURRENTS INDICATES FAULT CONDITION.	NOT GIVEN NOT GIVEN	← NO OTHER DATA OR INFORMATION PROVIDED →			OPERATION EXPLANATIONS WERE PROVIDED IN BOTH THESE DEVICES	• IN A VERBAL DISCUSSION WITH THE COMPANY, IT WAS QUOTED THAT APPROXIMATELY $25,000 WAS THE COST OF DEVELOPING THE GROUND FAULT & DYNAMIC TRACTION MOTOR PROTECTION SYSTEM PROTOTYPE MODEL. • THE OWNER OF THE COMPANY REFUSES TO RELEASE ANY OTHER INFORMATION.

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-5 of C-9
By N. Sagar Date
Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
• GEC TRANSMISSION & DISTRIBUTION PROJECTS (GEC) STAFFORD, ENGLAND	X			•RATE OF RISE RELAY 3R-1A	•RATE OF RISE CURRENT PRINCIPLE IN EXCESS OF PRESET LEVEL	$600 + ADD'L. EXPENSES FOR INSTALLATION ON MODIFICATION OR PURCHASE OF NEW EQUIPMENT	← NOT RESPONDED TO →			•USED ON MTRC HONG KONG, WMCC MEGLAV BIRMINGHAM AIRPORT ENGLAND, & CARACAS METRO IN VENEZUELA	← NO OTHER DATA OR INFORMATION PROVIDED →							
• ENGLISH ELECTRIC CORP. (EEC) PORT CHESTER, NEW YORK, U.S.A.				•INVERSE TIME RELAY ITR-1A	•INVERSE TIME RELAY CAN TRIP LOW LEVEL FAULTS IF PERSISTED FOR A LONGER THAN PRESET TIME.	$600 + ADD'L. EXPENSES												

MAIN Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-6 of C-9
By N. Sagar Date
Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
MEIDENSHA ELECTRIC MFG. CO. LTD. TOKYO, JAPAN (SUPPLIER)	X			●FAULT SELECTIVE DEVICE MODEL FE-13 ●DC FDR. CURRENT ANALYSIS DEVICE MODEL Al-3F RATED @3000A DC ●BOTH ABOVE DEVICES ARE MFRD. BY TSUDA ELECT. MFG.CO. OF OSACA, JAPAN	● Δi PRINCIPLE ● Δi PRINCIPLE MEASURING INCREASING Δi ON EACH FEEDER & HAS BUILT-IN COUNTER	●AS OF NOV. 15, 1983 $3700 (FOB JAPAN) ●AS OF NOV. 15, 1983 $8000 (FOB JAPAN)	NONE PROVIDED BUT STATED WE SHOULD PROVIDE THEM TECHNICAL DATA FOR INDIVIDUAL SYSTEM			DELIVERY 4 MONTHS	◄— NONE PROVIDED —►							●PROVIDED RESPECTIVE INSTRUCTION BROCHURES FOR BOTH THE DEVICES. ●A LONG LIST OF CUSTOMERS IS PROVIDED WHICH INCLUDED PUBLIC, PRIVATE, GOVERNMENT RAILROADS, UTILITIES, ELECT. MFRS., INDUSTRIES, ETC.

MAIN

Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-7 of C-9

By N. Sagar Date

Chkd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
MERLIN GERIN GRENOBLE, FRANCE	← SEE COMMENTS →																	• THE COMPANY WAS CONTACTED BASED ON THE REFERRAL FROM THE U.S. BUREAU OF MINES - PITTSBURGH, PA, U.S.A. • THE RESPONSE STATED THAT IT HAS STOPPED MAKING TRACTION EQUIPMENT. • FORWARDED OUR QUESTIONNAIRE TO JEUMONT SCHNEIDER, ONE OF THE LEADERS IN TRANSIT SYSTEM (CONTACT MR. FILLIATRE). • NO RESPONSE WAS RECEIVED FROM REFERENCED COMPANY.

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Client NATIONAL ACADEMY OF SCIENCES
Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS
SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS.

Job No. 3819 Sheet C-8 of C-9
By N. Sagar Date
Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
MITSUBISHI ELECTRIC CORP. TOKYO JAPAN (SUPPLIER)	X			TSUDA ELECTRIC METER CO MFR. FAULT SELECTIVE DEVICE FOR DC FEEDERS MODEL FE-13	Δi CHARACTERISTICS	AS OF NOV.14' 1983 FAULT SELECTIVE RELAY JP¥795 THOUSANDS AND FAULT DETECTOR JP¥400 THOUSANDS TOTAL . JP¥ 1,195,000 (EQUIV. $5306)		X	NONE PROVIDED	MODEL FE FAULT SELECTIVE DEVICE USED BY ●JNR (1230 SETS) ●PUBLIC RAILWAYS (259 SETS) ●PRIVATE RAILWAYS IN JAPAN (461 SETS) WHILE KOREA, CHINA, INDIA, NEW ZEALAND, AUSTRALIA ARE USING TOTAL OF 2772 SETS.	← NONE PROVIDED →							●INSTRUCTION MANUAL DE-044 IS PROVIDED. ●TWO RELAYS BOTH TO BE MOUNTED ON DC BREAKER.

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Client NATIONAL ACADEMY OF SCIENCES

Subject NCTRP PROJECT-43-1 LOW CURRENT SHORT CIRCUITS

SUMMARY OF SURVEY RESPONSES OF EQUIPMENT MFRS/SUPPLIERS

Job No. 3819 Sheet C-9 of C-9

By N. Sagar Date

Chd. Rev.

EQUIPMENT MFR./SUPPLIER	LCFD EQUIP OFFERED TO INSTALL			LCFD IN TPS							LCFD ON-BOARD TRAIN							COMMENTS
	IN TPS	ON BOARD TRAIN	OTHER	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	DEVICE MODEL NO.	OPERATING PRINCIPLE	EST. PRICE	ANY CHANGE TO THE SYSTEM REQUIRED?			PERTINENT DATA OR ADDITIONAL INFO.	
							NO	YES	DETAILS					NO	YES	DETAILS		
• SIEMENS ELECTRIC LTD. POINTE CLAIR, QUEBEC, CANADA AND • SIEMENS-ALLIS, INC. ATLANTA, GA	X	–	FOR INDUSTRY	•3UB51 RELAY W/THE CURRENT TRANSF. 3UB544 IS PROVIDED IN CONJUNCTION W/3WV TYPE DC BKR. MFRD.BY SIEMENS. •3UB5817 FOR INDUSTRIAL APPLICATIONS.	di/dt	•CANADIAN $ 2000 FOR 3UB5121 •CANADIAN $ 2700 FOR 3UB5137 di/dt RELAYS •CANADIAN $ 650.00 FOR 3UB5443 & CANADIAN $ 1500 FOR 3UB5444 CURRENT TRANSFORMERS. •CANADIAN $ 360 FOR FABRICATION IN 3WV SWGR. •EXTERNAL INSTAL. EXTRA •PRICE EXCLUDES TAXES & FREIGHT	← NO OTHER DATA OR INFORMATION PROVIDED →			•SEEMS MOSTLY PROVIDED WITH THEIR OWN BKR. THOUGH FEASIBLE TO ADOPT OTHER BKRS. •STATED THAT ADJUSTMENT TESTS HAVE BEEN EXECUTED WITH MOST CUSTOMERS BUT REPORTS NOT SUITABLE TO PUBLISH. •BEING FURNISHED IN THE SWGR. PROVIDED TO TRI-MET PORTLAND, OREGON.	← NO DATA PROVIDED →							•A COMPLETE BROCHURE EXPLAINING ALL TECHNICAL DETAILS AND SETTINGS IS PROVIDED TOGETHER WITH CURRENT TRANS. AND DC BKR. DATA. •SIEMENS-ALLIS (BRAINTREE, MA OFFICE HAS INFORMED THAT A COUPLE OF 3UB51 RELAY ASSEMBLIES WERE LOANED TO MBTA. NO FEEDBACK FROM MBTA WAS MADE AVAILABLE FOR THE PERFORMANCE.

APPENDIX D

SUMMARY OF RESPONSES FROM PROFESSIONAL ASSOCIATIONS

Professional associations that provided either no response or a negative response are listed as follows:

Professional Associations	*No Response*	*Negative Response Stating No Activity*
• Research Design & Standards Organization Ministry of Railways, India	X	
• Union of African Railways, Zaire	X	
• Australian Railway Research & Development Organization, Australia		X
• Latin American Railway Association, Argentina	X	
• Association des Fabricants Europeens d' Equipments Ferroviaires, France	X	
• Japan Railway Electrification Association Inc., Japan	X	
• Institute of Electrical Engineers, England	X	
• Association Internationale de Congres des Chemis de Fer, Belgium		X
• Chartered Institute of Transport, England	X	
• American Public Transit Association, U.S.A.	X	
• Power Conversion Products Council, U.S.A.		X
• National Association of Relay Manufacturers, U.S.A.		X
• National Electrical Manufacturers Association, U.S.A.	X	
• Institute of Electrical and Electronics Engineers, Protective Relaying Committee, U.S.A.		X
• Edison Electric Institute, U.S.A.		X
• Association of American Railroads, U.S.A.		X
• American Railway Engineering Association, U.S.A.		X

Responses with referrals are noted in the following:

Association	*Referral To*
• Japanese Railway Engineers Association, Japan	• Japanese National Railways • Response received and summary are included in Appendixes B and F.
• Canadian Urban Transit Association, Canada	• Toronto Transit Commission • Montreal Urban Community Transit Commission • The City of Calgary—System • The City of Edmonton—System • Responses received and summary are included in Appendix B.
• U.S. Department of Labor, U.S.A.	• USDOL, Office of Mine, Safety & Health • Followed up with referrals of USDOL, Research Center in W. Va.
• Union of European Railway Industries, France	• The BN Company • The Faiveley Company • No responses received from these referrals.
• Association Internationale des Constructeurs de Material Roulant, France	• Provided the names, addresses, phone numbers, and telex numbers of European manufacturers, most of whom have been contacted by the Project.

Positive responses were received from the following:

1. National Transportation Safety Board, U.S.A., provided two reports (available from NTSB, Washington, D.C.) as follows:
   a. *Report No. NTSB-EE-81-1,* "Safety Effectiveness Evaluation of Rail Rapid Transit Safety."
      - Highlights public hearing of 25 witnesses testifying issues related to transit car design, emergency exit from car, emergency tunnel ventilation, evacuation from tunnel, emergency training, drilling and testing, emergency communications, equipment mobility and State/Local/Federal safety oversight of rail/rapid transit safety.

   b. *Report No. NTSB-STR-81-5,* "Special Investigation Report."
      - Highlights eight subway train fires on New York City Transit Authority with evacuation of passengers.

2. Texas A&M University, U.S.A., provided copies of papers written by Prof. B. Don Russell (*28, 29, 30*) summarizing low-current fault detection activity and Texas A&M involvement and participation. Some of the techniques suggested are included in Appendix E under the subsection of low-current fault detection with utilities.

APPENDIX E

SUMMARY OF RESPONSES FROM OTHER INDUSTRIES

Responses from utilities are noted in the following:

Utility Company	*No Response*	*Interested But No Activity or No Solution Found*
• Arizona Public Service Co., Arizona	X	
• Baltimore Gas & Electric Co., Maryland		X Prepared to meet with us, but no further data provided.
• Boston Edison Co., Massachusetts	X	
• The Dayton Power & Light Co., Ohio	X	
• American Electric Power, Ohio	X	
• Arkansas Power & Light, Arkansas	X	
• Bonneville Power Administration, Oregon		X
• Cambridge Electric Light Co., Massachusetts	X	
• Florida Power & Light Co., Florida	X	
• GPU Services Corporation, New Jersey	X	
• Juneau Utility Commission, Wisconsin	X	
• Nebraska Public Power District, Nebraska		X
• Delaware Power & Light Co., Delaware	X	
• Georgia Power & Light Co., Georgia	X	
• Gulf States Utilities, Texas	X	
• Los Angeles Department of Water & Power, California	X	
• Pacific Gas & Electric Co., California	X	
• New York Power Authority, New York	X	
• Tennessee Valley Authority, Tennessee		X
• New England Power Services Co., Massachusetts		X
• Ohio Edison Co., Ohio		X Referrals to Relaying Books and ANSI Standards
• Commonwealth Electric Co., Massachusetts		X
• San Diego Gas & Electric Co., California	X	
• Virginia Electric & Power Co., Virginia		X
• Wisconsin Power & Light Co., Wisconsin	X	
• Texas Utilities Company, Texas	X	
• Washington-St. Tammany Elect. Coop. Inc., Louisiana	X	

Positive responses were indicated by the following.

- Northeast Utilities Service Company (NUSCO), Connecticut, provided the following summary (*21*) of its approach for low-current faults by using a backup ground relay on multigrounded wye circuits.

> The expansion of the distribution system has results in desensitizing the ground relay due to unbalance currents and to maintain coordination with fuses. This has resulted in considerable

loss of sensitivity to low current faults. The use of a backup or a second ground relay with "long time" time-characteristics and a low pickup value provides approximately 50% increase in sensitivity without disturbing the normal mode of operation or existing system coordination.

In 1978 (5) backup feeder ground relays were installed by NUSCO and their performance was monitored through 1980 with very encouraging results.

The installation of a "long time" relay 51N B.U., Fig. E-1, connected in series with the standard ground relay 51N, produces a composite curve and restores the lost sensitivity as shown in Fig. E-2. These curves intersect at the time of ten seconds. Normal high current faults are cleared by reclosers, fuses, and the feeder breaker by its normal compliment of relays while maintaining complete coordination and permitting normal reclosing operations on both breakers and reclosers.

A fault remaining on the system for more than ten seconds will be cleared by the backup relay which operates a lockout relay 86 to trip and prevent reclosing operations.

The pickup value of the backup relay was determined by measuring the normal unbalance with a recording ammeter installed in the relay neutral circuit and by evaluating the circuit unbalance when the largest single phase device was open. Through test installations, the pickup value of the relay was determined as 120 amperes.

The test circuits had reclosers and 140K fuses. Since this size fuse is used to maintain fuse to fuse coordination in high fault current areas and to permit recloser instantaneous elements to reach through the fuses for transient fault clearing, rarely does the load current reach 140 amps, therefore a blown fuse will not produce an unbalance condition sufficient to operate the backup relay.

DISTRIBUTION BACK-UP FEEDER GROUND RELAY (21)

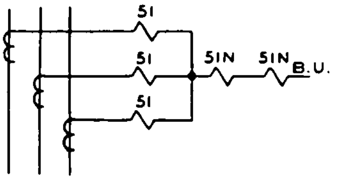

FIG. E-1

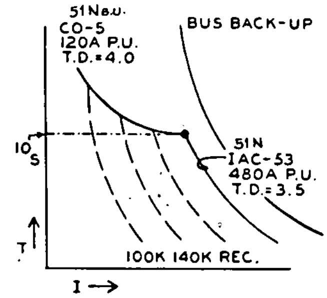

FIG. E-2

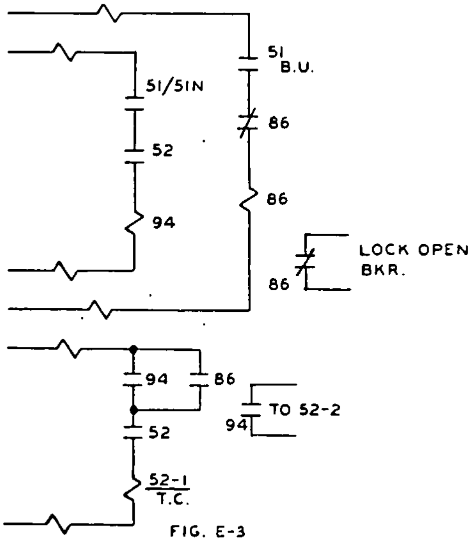

FIG. E-3

A typical 15 or 25 kV distribution circuit may have a day to day level of 200 to 250 amps with both line to neutral and ground wye-wye loads. When a conductor comes down on the main trunk the backup relay may operate from sustained fault amperes of 120 to 600A, by load unbalance alone or a combination of both.

The time dial setting of (4) will cause the relay to reset in (30) seconds at zero amps. With any current in the relay, the reset time is extended. This in effect permits fault information to be stored in the disc during an intermittent fault. When fault contact is made, the disc will advance and very little reset activity will occur when the fault is removed. The disc then is advanced in steps towards trip.

This backup relay then is capable of initiating a tripping operation as follows:

a. Sustained fault current between 120 and 600A
b. System unbalance exceeding 120A
c. Combination of both a. and b. above
d. Advancing the disc in steps for intermittent faults

An additional function is available if a 94 tripping relay is used. Contacts of the backup relay are wired to its own D.C. source remote from the normal relay components. This then provides a true backup for a failure of the 94 to a blown D.C. fuse including a breaker auxiliary contact out of adjustment. See Fig. E-3.

All designs of this type have their disadvantages and this is no exception. If load unbalance can initiate tripping for a downed conductor, it follows that an open tie will also initiate tripping. The impact may not be too objectionable if we consider that prolonged single phasing to the three phase loads would not occur. Also, the relay will have to be deactivated during single phase switching. Monitoring the system when new loads are added or transfers take place is important and will require attention.

There is no doubt that an occasional fault will occur beyond fuses and reclosers which will trip the circuit by backup relay.

An occasional false trip does occur with the normal protective devices though the disadvantages do not outweigh the advantages. An occasional false trip should be acceptable.

This design, even with its weaknesses, will greatly improve the systems capability to detect low current fault conditions. Standard components are used, its installation is routine and it's economical.

NUSCO anticipates applying the same backup philosophy to pole mounted electronic reclosers. This will provide two levels of "long-time" coordination so that downed conductors beyond reclosers will not trip the feeder breaker.

- The Pennsylvania Power & Light Co. (PP&L Co.) in conjunction with Westinghouse Electric Corporation has conducted several study projects in the subject area. The Electrical Power Research Institute (EPRI) has sponsored at least three projects for utilities in the "Detection of High Impedance Faults on Distribution Circuits.".

Relevant copies of papers published since 1975 and the EPRI reports were received by the project research team. A review of the papers and reports reveals that the utilities have a more complex problem because of other parameters involved in addition to simply a resistance problem in the case of transit systems. Nevertheless the utilities have tried to perform the analysis in various ways to seek a solution, but unfortunately the universal solution has not yet been found. Also, no information or estimate regarding the cost of the prototype system has been made available. The paper entitled, "Summary and Status Report On Research To Detect and De-energize High Impedance Faults On Three Phase, Four-Wire Distribution Circuits," by R. E. Lee of PP&L Co. and L. A. Kilar of Westinghouse, gives satisfactory details of utilities' pursuits, and PP&L's and Westinghouse's approaches to high impedance fault detection.

Copies of two additional papers are also included stating the summary of development, testing and performance of a prototype electromechanical relay called "Ratio Ground Relay." These papers are: "Summary Development and Testing of an Electro-mechanical Relay to Detect Fallen Distribution Conductors," by Calhoun, Bishop, Eichler and Lee; and "Summary for Performance Testing of the Ratio Ground Relay on a Four-Wire Distribution Feeder by Lee and Bishop.

SUMMARY AND STATUS REPORT ON RESEARCH TO DETECT AND DE-ENERGIZE HIGH IMPEDANCE FAULTS ON THREE-PHASE, FOUR-WIRE DISTRIBUTION CIRCUITS

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Abstract - A summation of activities, within the electric utility industry, directed toward the discovery of a method or methods to detect and clear high impedance faults on three-phase, four-wire distribution circuits. A number of innovative relay schemes, as evaluated on Pennsylvania Power & Light's distribution system, are discussed and their relative abilities to detect high impedance faults when compared with conventional relay schemes are presented.

INTRODUCTION

Fault protection, as practiced by the electric utility industry on distribution circuits, generally depends on current sensing. Overcurrent protection is achieved using fuse links, overcurrent relays, and ground relays to detect the fault and to signal circuit interrupting devices such a cutouts, reclosers, and circuit breakers to interrupt current flow. Phase overcurrent relay settings must be above load currents and ground overcurrent relay settings must be above expected unbalanced phase currents. A high degree of coordination has been achieved using these devices to provide quick isolation of a faulted line section with minimum disturbance to other portions of the circuit.

Most electric utility customers are served from single phase transformers connected to four-wire solidly grounded overhead distribution circuits in the 15kV class. Overcurrent devices will not detect certain faults, such as a broken conductor or a conductor in contact with a foreign object, on these systems because fault current magnitudes are restricted by the high impedance of the contacted surface, or by arc impedance. Overcurrent devices set low enough to detect these faults will not meet coordination and load carrying requirements. These faults, while not so destructive to the systems themselves, can cause extended service interruption to customers and, under certain conditions, may be hazardous to public safety.

High impedance faults may occur in one of four configurations:

1) Phase conductor broken with source side touching earth and load side clear.
2) Phase conductor broken with source side clear and load side touching earth.
3) Phase conductor broken with both ends clear, causing an open circuit in one phase.
4) Foreign object, such as a tree branch touching one or more phase conductor.

Adequate, reliable detection of high impedance faults has not been achieved using current sensing devices. Other circuit characteristics, individually or in combination, are subject to change during high impedance faults. Such changes must be reliably distinctive and observable (detectable) during the occurrence.

In 1965 Pennsylvania Power & Light Company adopted an alternate overhead line design using cross-linked polyethylene (XLP) covered aluminum and ACSR conductors. By the early 1970's, failures of XLP covered conductors became prevalent enough to cause great concern. In many instances the circuit protective devices failed to interrupt the faults.

PENNSYLVANIA POWER AND LIGHT COMPANY'S ACTIVITIES

1. East Allentown Test [1]

In October 1973 alteration of the substation breaker reclosing schedule was tested as a possible solution. Staged fault tests, using bare and XLP covered conductors lying on several "ground" surfaces, were conducted to determine typical current magnitudes for conductor faults as compared to bare conductor faults, to observe the typical behavior of the fault current as a function of time, and to develop a method for clearing covered conductor faults using the acquired test data.

Results of the tests at PP&L's East Allentown 66/12kV Substation were entirely unexpected. There was never sufficient fault current flowing to trip the substation circuit breaker with either bare or XLP covered conductors lying on the ground surfaces. Subsequent calculations indicated that a ground relay set at 50 amps, or lower, would have been required to detect the faults.

2. Distribution Fault Interruption Task Force

These tests at East Allentown Substation proved that changing relay settings would not solve the problem. Consequently, a task force was assigned to study and define the problem and seek a solution.

The questions considered were:

1) What is the Magnitude of the Problem on the PP&L System? [2]
   High impedance fault data on the PP&L distribution system was collected between April 1974 and December 1975. Included in the resulting data file of 390 cases of high impedance faults were: fault location, conductor type and size, load or source end of conductor on the ground, type of surface contacted, and size of protective device involved, position of protective device (open or closed), protective device settings and ratings, and the calculated available bolted fault current at the fault location.
2) What Physical and Electrical Conditions are Associated with High Impedance Faults?
   PP&L overhead distribution system, approximately 31,000 circuit miles, is comprised of lines constructed with bare conductor-95%-and XLP covered conductor 5%. Bare conductors were involved in 83.5% and XLP covered conductors in 16.5% of the 390 high impedance faults.One hundred twenty-three (123) faults were not interrupted,bare conductor accounted for 62% and XLP covered conductor for 68%.

A 79 516-6 A paper recommended and approved by the IEEE Transmission and Distribution Committee of the IEEE Power Engineering Society for presentation at the IEEE PES Summer Meeting, Vancouver, British Columbia, Canada, July 15-20, 1979. Manuscript submitted February 5, 1979; made available for printing May 11, 1979.

This documented an existing problem with bare as well as XLP covered conductors. The types of protective devices involved in the failures to interrupt high impedance faults were: substation circuit breaker - 52%, three phase reclosers-18%, single phase reclosers - 13%, and single phase fuses - 17%.

There is no apparent correlation between the ability of a protective device to operate and: contacted surface, proximity of pole grounds, size and type of conductor, and available fault current.

The occurrence of and inability to detect and interrupt high impedance faults was proven to be much greater than realized. Seventy percent (70%) of the failures to interrupt faults were protected by three phase devices.

Fault current was proven to be an unreliable fault characteristic to detect high impedance faults and some other fault or circuit characteristic must be monitored.

3) Are other Utilities Experiencing the Same Problem?

Responses, from two questionnaires, from the Edison Electric Institute Transmission and Distribution member companies confirmed that high impedance fault interruption is an industrywide problem. Seventy-three percent (73%) responded that they encountered difficulty in fault interruption while 21% reported infrequent failures to interrupt.

4) Has some other Utility Found a Solution?

About 81% of the EEI companies in the 11.5 to 13.8kV class using multigrounded distribution circuits reported that they use ground as well as phase overcurrent relays.

Ground relaying on the PP&L system has long been considered unrealiable and of questionable value to PP&L because of the high setting level required by load unbalance, the unpredictable ground currents that can be encountered due to the wide use of grounded wye-delta transformer banks, and because of probable undesirable false tripping.

Answers to three of the questions were relatively easy to acquire. Determining the physical and electrical characteristics has been elusive, but, progress has been made.

3. Zero Sequence Voltage Tests [3]

Detection of unbalanced voltages under fault conditions was suggested as a possible solution. Calculations indicated that significant unbalances occur during some high impedance fault conditions. Lengthy calculations verified this hypothesis. Another series of tests were conducted in October 1975 to verify these calculations by investigating zero sequence voltage.

The objectives of these tests were to:

1) Measure unbalanced voltage (V_o-zero sequence voltage) at several locations on a working 12 kV line.
2) Gather data to help develop a method to detect high impedance faults using zero sequence voltage.
3) Determine the existence of other circuit characteristics that would be useful in detecting high impedance faults.

For the tests, a 12kV three phase circuit was needed where an infinite impedance fault could be simulated without interrupting any customers. A line section protected by a three phase 225 ampere OCR with three single phase load break bypass switches supplying two large grounded wye-delta transformer banks serving an asphalt plant and a rock crusher met the requirement. These banks had sufficient capacity to carry all the additional load when one phase at the OCR was opened, allowing the tests to be conducted without customer interruption. The line section also supplies several other small and medium size industrial and commercial customers as well as numerous residential customers and a medium density residential area. A 1200 KVAR switched capacitor bank provides voltage correction for the line.

The unusually large capacity (1333 KVA) of the grounded wye-delta transformer banks limits the voltage unbalance under fault conditions, thus creating a "worst case" condition.

Prior to the test, phase currents, phase-to-ground voltages, neutral current and zero sequence voltage were recorded to determine "system normal" conditions as well as high, medium and low load conditions.

On the day of the test, additional instrumentation was installed to measure phase angles and make oscillograph recordings of the three phase-to-ground voltages and zero sequence voltage at the line end.

Infinite impedance (open conductor) faults were simulated by closing two OCR bypass switches and then opening the OCR, thus leaving one phase conductor open.

Conclusions and observations obtained from the test data were:

1) The calculation of zero sequence voltages was verified by the test data.
2) For the test conditions, a voltage relay could detect the change in zero sequence voltage between system normal and faulted, and initiate interruption of the circuit.
3) A Fourier Analysis of the oscillographs showed changes in the harmonic content of the phase-to-ground voltages between system normal and system faulted conditions. Work being conducted by Rochester Gas & Electric Company substantiates this.
4) Changes in current phase angles were also observed.
5) A computer program capable of performing the complex calculations involving distribution systems was required.

4. Distribution Fault Analysis Program

An operational computer program that calculates steady state voltages, current flows and phase angles at modeled buses of a distribution circuit in phasor notation has been developed. The program allows modeling of a complete radial distribution circuit using unbalanced distributed loads, capacitor banks, grounded wye-delta transformer banks, single and two phase lines as well as three phase lines. It calculates system normal conditions, single or multiple phase-to-ground faults, single or multiple open conductor faults with or without phase-to-ground faults on load or source side. Fault impedance can be included with any of the phase-to-ground fault conditions. Faults can be imposed singly, in combination at a location, or in widespread simultaneous occurrences.

Solution of the defined model is accomplished by formulating a system of non-linear algebraic equations known as the load flow problem. Additional equations, required to define the grounded wye-delta transformer banks were taken from papers published by Dr. M. A. Laughton. The load flow problem solution is calculated using the Gauss-Seidel iterative techniques as outlined in Computer Methods in Power System Analysis by Stagg and El-Abiad.

Upon completion of the Distribution Fault Analysis Program, a data set representative of a "typical line" was created. A large variety of calculations were performed using this test line to gain experience with the program, investigate sensitivity to fault impedance and grounded wye-delta transformer bank size and location, and to acquire a feel for characteristic circuit changes during fault conditions.

Some circuit characteristics were immediately obvious. They are negative and zero sequence voltage beyond the open conductor fault and negative and zero sequence current at the protective device responsible for detecting the open conductor fault.

5. PP&L-Westinghouse Joint Reserarch [4]

Six promising relay schemes and ground relays were studied by PP&L and the Advanced Systems Technology Division of Westinghouse Power Systems Company. Each scheme was evaluated, by computer simulation of the relay schemes and six distribution circuits at three load levels, in terms of its technical performance under simulated fault conditions and its estimated installed cost. Comparison with PP&L's existing protective scheme was made to estimate the cost effectiveness of the proposed relay schemes.

Any protective device or scheme to detect high impedance faults should possess the following characteristics to be acceptable to the electric utility industry: sensitive, discriminative, reliable, secure, economic, rugged, relatively simple, easy to apply, fast installation and low maintenance. Some of the solutions considered, but found deficient, were:

1) Mechanical Tension Sensors.
2) Fault Enhancers.
3) Fiberoptics.
4) Reflectometry.
5) DC Injection.
6) Electrical Transients.
7) Radio Frequency Noise.

Relay schemes, selected on their capabilities to satisfy these characteristics and based on different operating quantities, were selected for study as follows:

1) Ratio Ground Relay (RGR) - The RGR is a device in which the sensitivity of a ground relay varies proportionately to phase current unbalance. It can be accomplished by designing a device responsive to the ratio of zero to positive sequence currents, I_o/I_1. Figure 1 shows the block diagram representation of the proposed system. The ratio unit extract I_1 and I_0 from the phase and neutral currents. This unit produces an output only if I_o/I_1 is greater than a prespecified value. The D_0 unit determines the position of the fault with respect to the RGR. If the fault is downstream from the RGR (point B), D_0 will provide an output which, together with the output from the ratio unit, will activate fast timer T_1. If the fault is upstream (point A), the output of the ratio unit alone will activate the slow timer T_2, providing time for a protective device ahead of the RGR to operate first.

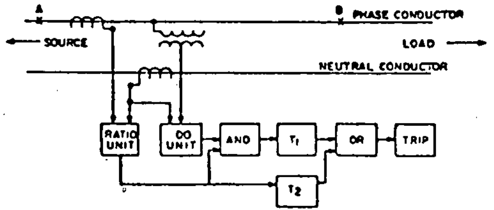


Fig.1 - Ratio Ground Relay System

2) Undervoltage Relay - Appreciable loss of voltage occurs at the end of a line from most high impedance faults, although large grounded wye-delta connected transformer banks tend to maintain normal voltage on the faulted (open conductor) phase. An undervoltage relay at the end of a feeder can be made to pick up on low voltage and initiate communications to trip the appropriate protective device. (Fig.2)

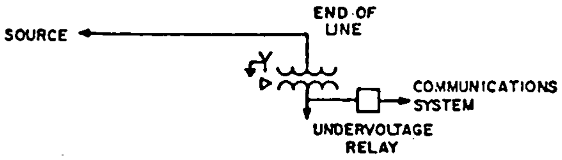
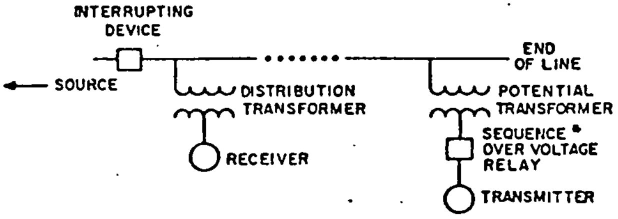


Fig.2 - Undervoltage Relay Scheme

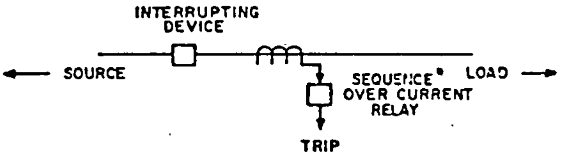
3. & 4) Zero and Negative Sequence Overvoltage Relays
Abnormal zero and/or negative sequence voltages occur downstream from a high impedance fault due to unbalanced voltage conditions. A zero or negative sequence overvoltage relay can be used to detect abnormally high sequence voltages and initiate tripping of an interrupting device through an appropriate communications link which could vary depending on several technical and economic factors. (Fig.3)



* Zero or Negative

Fig.3 - Zero and Negative Sequence Overvoltage Relay Scheme

5. & 6) Zero and Negative Sequence Overcurrent relays
A high impedance fault may cause heavy current unbalance upstream from the fault location. Zero or negative sequence overcurrent relays can be applied at the protective device to detect these abnormally high sequence currents. (Fig.4)



* Zero or Negative

Fig.4 - Zero and Negative Sequence Overcurrent Relay Scheme

Typical quantities, Table I, for the various relay scheme operating charecteristics were selected from operating experience, staged tests and calculations.

TABLE I - TENTATIVE RELAY SETTINGS

Scheme	Relay	Setting
Phase Undervoltage	CV1*	Tap = 210 Volts T.D. = 4
Zero Sequence Overvoltage	CV8*	6 V Pick up, 2.8 Sec. at 10 x Pickup
Negative Sequence Overvoltage	CVQ*	6 Volts, Instantaneous
Zero Sequence Overcurrent	ITH*	50 Amps[1] at Substation, 12 Amps[1] at OCR Instantaneous
Negative Sequence Overcurrent	SSQ*	50 Amps[1] at Substation, 12 Amps[1] at OCR Instantaneous
Ground Overcurrent	IAC-57**	180 Amps Pickup, 5.25 Sec. at 10 x Pickup
Phase Overcurrent	CO-7*	600 Amps Pickup, 0.5 Sec. at 10 x Pickup
Ratio Ground Relay	-	Min. Ratio = 0.15 135° ≤ Op. Zone ≤ 315°

[1] Assuming these settings are available

*Westinghouse

**General Electric

The Distribution Fault Analysis Program was used to calculate phase voltages and line current flows for each of nine "fault" conditions at various locations on six circuits at three load levels (low, medium, high), representative of PP&L's distribution system. Grounded wye-delta transformer banks were included in the calculations. The nine "faults" were: (Fig.5)

1) Normal Conditions.
2) Phase-to-Ground.
3) Two Phases-to-Ground.
4) Three Phases-to-Ground.
5) One Phase Open.
6) One Phase Open, Source Bus Grounded.
7) One Phase Open, Load Line Grounded.
8) One Phase Open, Load Bus Grounded.
9) One Phase Open, Source Line Grounded.

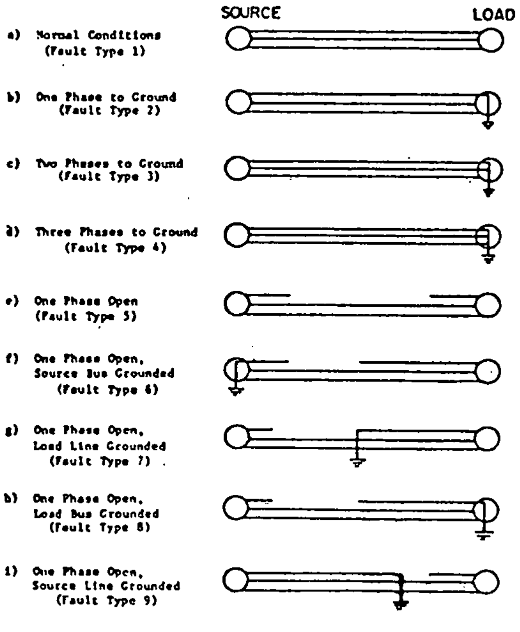


Fig. 5 - Fault Types Studied

A Relay Evaluation Program was developed to simulate the behavior of the six proposed relay schemes as well as the customarily used station circuit breakers and reclosers. Since many utilities use the ground relay and trials were beginning, it was also simulated. The response (no attempts at coordination were made) of each relay scheme at different locations was evaluated in terms of percentage of faults cleared for high impedance faults and overall.

Fault types 5, 7, and 8 closely represent fallen conductors which, presently, are difficult to detect. Table II shows the effectiveness of detection for each relay scheme as a percentage of faults detected for fault types 5, 7, and 8.

From Table II, it may be concluded that negative or zero sequence overvoltage sensing at the ends of feeders and branches would be the most effective method to detect broken and/or fallen conductors in distribution circuits. However, the end-of-line sequence overvoltage schemes have various disadvantages:

1) Several sensing locations, each requiring a communications system, will be necessary to cover the main feeder and its branches.
2) Receiver equipment will be necessary at the protective device.
3) Total reliability of the scheme may be lower than required.
4) The ends of lines or branches are dynamic positions that may require regular relocation of the relays and related equipment.
5) Total cost per feeder is presently very high.

When automated distribution systems (ADS) become fully available and operational, data transmission/reception could be done via two ADS stations, sharply reducing the total costs for this relay scheme.

TABLE II

PERCENTAGE CORRECT OPERATIONS
FOR THE PROPOSED SENSING DEVICES
UNDER FAULT TYPES 5, 7, AND 8

Fault Type / Device	5	7	8
Ground Relay at Substation	35.96	49.12	48.25
Neg. Seq. Current at Substation-Low Setting	54.39	69.30	69.30
Neg. Seq. Current at OCR's	54.39	84.21	84.21
Neg. Seq. Current at Substation-High Setting	21.93	45.61	45.61
Zero Seq. Current at Substation	46.49	56.14	47.37
Zero Seq. Current at OCR's	61.40	70.18	70.18
Neg. Seq. Voltage at Branches	92.55	100.00	100.00
Neg. Seq. Voltage at Main Feeder	100.00	100.00	100.00
Zero Seq. Voltage at Branches	92.55	100.00	100.00
Zero Seq. Voltage at Main Feeder	100.00	100.00	100.00
Phase Undervoltage at Branches	84.06	100.00	100.00
Phase Undervoltage at Main Feeder	86.72	100.00	100.00
RCR at Substation	74.56	83.33	83.33
RCR at OCR's	96.03	97.22	97.22

Conclusions of the study are:

1) The phase overcurrent protective devices now used for distribution circuits are ineffective in detecting and clearing high impedance faults.
2) A solidly grounded fallen phase conductor, whether broken or not, will produce detectable voltage unbalance downstream from the fault location.
3) An ungrounded broken conductor will produce detectable voltage unbalance downstream from the fault location.
4) Broken and/or solidly grounded conductors will cause current unbalance upstream from the fault location.
5) Ground overcurrent relays would detect only about 40% of the high impedance fault types.
6) Monitoring of negative sequence overvoltage at the end of a circuit provides a secure means of detecting broken and/or grounded conductors in that line section. Almost perfect performance can be expected from these schemes.
7) The Ratio Ground Relay concept can be used as a method to detect current unbalance in a distribution circuit. The detection effectiveness is approximately 80%.
8) If cost is not the primary factor, sensing of negative sequence overvoltage at the ends of a feeder and its branches would be the most effective technique to detect broken and/or grounded conductors in a distribution circuit.

6. Ground Relay Installation

Concurrent with development of the Distribution Fault Analysis Program, the Task Force formulated a proposal to study the effectiveness of ground relays as applied to the PP&L distribution system. We estimated a possible 30% improvement in the detection, at the substation breaker, of high impedance faults. Later studies indicate a possible 37.5% improvement in detection.

It was proposed to install ground relays at 12 substations equipped with SCADA (Supervisory Control and Data Acquisition) to gather data.

Objectives of the proposal were:

1) Determine application guidelines for PP&L applications.
2) Evaluate dependability and security of the trial installations.
3) Evaluate costs and benefits.

The proposal was postponed. However, during the last quarter of 1978 PP&L began installing ground relays with new substation breakers. Approximately 72 new breakers with ground relays are being purchased for installation through 1980. Twenty-one (21) were placed in service in 1978. There have been no reported operations.

EPRI ACTIVITIES

Realizing that industry research was required, PP&L and Rochester Gas & Electric presented the problem with supporting data to the Electric Power Research Institute and IEEE.

The IEEE Power Systems Relaying Committee formed the Parameters of Distribution Ground Fault Protection Working Group which prepared, during 1976, a report to EPRI which formed the basis for a research project.

In 1977 EPRI issued Request For Proposal 5379 which had as its primary objective to develop a device, scheme, or system that will reliably detect high impedance faults on solidly grounded wye-connected, low-voltage distribution circuits. A secondary objective was to detect high impedance faults on ungrounded distribution circuits. Proposals submitted by eight research organizations covered periods of two to three years.

PP&L and RG&E are continuing independent paths toward a solution(s).

EPRI is now sponsering three research projects, "Detection of High Impedance Faults on Distribution Circuits". Three contracts were awarded to:

1) Power Technologies, Incorporated(RP-1285-1)[5]

The scope of this project is to make a thorough investigation of the changes in all electrical parameters when a high impedance fault occurs on a distribution system. By means of statistical analysis methods, parameters will be selected upon which to base the design of a high impedance fault detection instrument, and design specifications will be prepared. (24 months)

2) Hughes Aircraft Company (RP-1285-2)[5]

The contractor has proposed to develop a high impedance fault detection instrument based on the change of a third-harmonic current which occurs on a distribution system when a high impedance fault takes place.

The scope of this project is to develop and test a device designed on this concept. (30 months)

3) Texas A&M Research Foundation (RP-1285-3)[5]

The contractor has proposed to develop a high impedance fault detection instrument based on variations of the noise frequency components of the voltage and current waves which occur during high impedance faults.

The scope of this project is to complete the development and test the instrument. (24 months)

RELATED EPRI WORK

A project closely related to the EPRI Detection of High Impedance Faults is EPRI RP-1209-1, "Distribution Fault Current Analysis," [6] which was awarded to Power Technologies, Incorporated.

The continuing demand for electric power has made it necessary to increase ratings of system components. This, in turn, causes a marked increase in fault current duty on all system equipment. The theoretical maximum fault current can be calculated for any particular system location. However, reliable data to establish the actual values of fault currents experienced is not presently available. While it is well known that almost all faults produce currents below calculated values, the actual magnitudes, fault characteristics, or frequency of occurrence is not generally known. The lack of this type of test data results in imprecise system and equipment design, incorrect selection of equipment, and a strong tendency to conservative application of protective devices.

The objectives of this project are twofold:

1) To make available to the electric power industry comprehensive statistical data on fault currents as they are actually experience on primary distribution systems.
2) To investigate the current transients which occur when circuits are energized and to get statistical data on cold load pickup currents.

SUMMARY

In 1974 PP&L formed a task force to investigate means of positively interrupting faults caused by broken primary conductors falling to the ground. The first year's activities were directed toward defining the scope of the problem, and developing a course of action.

1975 activities produced industrywide recognition and better definition of the scope of the problem with some possible solutions being suggested. Further investigation confirmed that little information relative to possible solutions exists within the industry.

Company tests suggested the presence of circuit characteristics other than overcurrent which could initiate fault interruption while the data on fallen conductor faults established a sufficient base to warrant discontinuing its further collection.

During 1976 PP&L contributed to the formulation of an EPRI Work Statement, developed a test procedure to allow evaluation of ground relay applications on PP&L distribution circuits, and made significant progress in developing the Distribution Fault Analysis Program.

1977 was a year when we realized the fruits of our efforts in stimulating industry interest. EPRI issued a Request for Proposal for the "Detection of High Impedance Faults on Distribution Circuits". PP&L also joined with the Advanced System Technology Division of Westinghouse in a joint research project, "Feasibility Study of Improved Relay Schemes for the Detection of Fallen Conductors on Three-Phase Four-Wire Distribution Circuits". Analytical studies of data from the Distribution Fault Analysis Program application to several circuits indicated that zero and negative sequence current at the circuit interrupting device, and zero and negative sequence voltage beyond the fault would provide improved recognition of high impedance faults.

1978 saw the completion of the PP&L-Westinghouse research project which substantiated earlier observations and provided several promising relay schemes. Also, EPRI awarded research contracts to Power Technologies, Inc., Hughes Research Laboratory, and Texas A&M University to investigate several promising aspects in the Detection of High Impedance Faults.

PP&L is planning to continue its efforts toward determining a possible solution utilizing the analysis of voltages and currents that are present on a 12 KV, four-wire, grounded wye-distribution system with three phase grounded wye-delta transformer banks. If justified, after additional analysis of the data from the joint study with Westinghouse, PP&L plans to develop prototypes of promising relay schemes and perform field and laboratory tests of their operation.

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[3] PP&L - Distribution Fault Interruption, Open Conductor Tests, October 20, 1975 - internal report.

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[5] EPRI - Schedule to Agreement, RP-1285-1, RE-1285-2, RP-1285-3, Detection of High Impedance Faults on Distribution Circuits.

[6] EPRI - Schedule to Agreement, RP-1209-1, Distribution Fault Current Analysis.

SUMMARY

DEVELOPMENT AND TESTING OF AN ELECTRO-MECHANICAL RELAY TO DETECT FALLEN DISTRIBUTION CONDUCTORS

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Abstract – If undetected by phase or ground overcurrent relaying methods, fallen distribution conductors or high impedance faults may be a fire hazard and a threat to public safety. Four promising relay schemes to detect these faults are evaluated using both digital and analog techniques and one scheme was chosen for prototype construction. In the light of economic and performance data, a prototype Ratio Ground Relay has been constructed for installation and testing on six Pennsylvania Power and Light distribution feeders.

THE DATA BASE

Six distribution circuits representing 86% of PP&L's 1200-1300 distribution feeders when studied at three load levels were used in over 500 digital short circuit studies. Feeder voltages and line currents at various points along the line were calculated for each of the following conditions:

1) Normal conditions
2) One phase to ground fault
3) Two phase to ground fault
4) Three phase to ground fault
5) One phase open, no line grounded
6) One phase open, source bus grounded
7) One phase open, load line grounded
8) One phase open, load bus grounded
9) One phase open, source line grounded

Ratio Ground Relay Schemes

Four ratio ground relay schemes were evaluated using a relay coordination program and data from digital fault studies. The selected scheme was chosen in the light of manufacturing and operating requirements. A protective relay scheme must be economical, permit construction in a standard relay case size, present a low burden to existing substation current transformers, and be simple to apply, test, and set. The relay must also be dependable, secure, selective, and sensitive. In the particular application of the Ratio Ground Relay, high speed is not a constraint provided reliable operation takes place with proper coordination with existing overcurrent devices.

Using the aforementioned relay characteristics as selection criteria, four Ratio Ground Relay schemes were identified as promising candidates for digital modeling and prototype construction. Each scheme uses the induction disc concept with operating and restraint windings. Contact closing torque in all schemes is produced by residual current ($3I_0$) in the operating winding. Contact opening torque is produced by a combination of phase, positive and/or negative sequence current in the restraint winding. The four restraint combinations modeled are:

i) Balanced sequence current difference restraint scheme

$$\text{Restraint Torque} = KN^2 \left(|\bar{I}_1|^2 - |\bar{I}_2|^2\right)$$

ii) Positive sequence restraint scheme

$$\text{Restraint Torque} = KN^2 \, |\bar{I}_1|^2$$

iii) A + B phase restraint scheme

$$\text{Restraint Torque} = KN^2 \, |\bar{I}_A + \bar{I}_B|^2$$

iv) A + B + C phase restraint scheme

$$\text{Restraint Torque} = KN^2 \left(|\bar{I}_A|^2 + |\bar{I}_B|^2 + |\bar{I}_C|^2\right)$$

Digital Modeling

Based on relay coordination studies, two settings were chosen to provide operation on a circuit unbalance ($3I_0/I_1$) of 0.5 and 1.0. The preferred Ratio Ground Relay scheme should detect 80-85% of the fallen conductors on PP&L's distribution system based on approximately 550 open phase faults examined.

The Prototype Relay

With manufacturing and actual operating considerations in mind, the $|\bar{I}_1|^2 - |\bar{I}_2|^2$ restraint coupled with a $|3\bar{I}_0|^2$ operating element on a single induction disc was chosen for prototype construction. The other schemes were rejected at this time since their construction would result in larger case size, higher cost, multiple cores or filters and reduced sensitivity.

Conclusions

Phase and residually connected overcurrent relays may not detect fallen conductors or high impedance faults on a distribution circuit. Increasing the ground relay sensitivity is unacceptable since false tripping may result due to normal load unbalance and blown single phase fuses.

Digital fault studies using six PP&L distribution feeders were performed in order to determine the settings and restraint element for a prototype Ratio Ground Relay. A prototype device was constructed which should detect 80-85% of the fallen conductors on PP&L's distribution system.

A staged fault test and long-term monitoring of the Ratio Ground Relay on six PP&L distribution feeders is planned.

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INTRODUCTION

A fallen distribution conductor may be a potential hazard to life and property because it often remains energized when in contact with a high impedance surface such as dry concrete or macadam. Fault currents in the 0 to 50 ampere range may result from fallen lines and could render the phase and ground overcurrent devices ineffective in the detection of high impedance faults.

Since 1973, Pennsylvania Power and Light Company (PP&L) has actively pursued solutions to the fallen conductor problem. Staged fault tests were conducted on covered and bare distribution conductors, data on broken and fallen conductors on their distribution system has been collected and a Distribution Fault Calculation Program, which determines vector quantities at all points of interest on a distribution circuit, was formulated. PP&L then proposed protective relays based on sequence quantities as promising candidates for fallen conductor detection devices.

In 1977, PP&L began a joint study with Westinghouse Advanced Systems Technology to assess the feasibility of various relay schemes for detection of fallen conductors (1). In addition to PP&L's sequence quantity relay schemes, Westinghouse developed the Ratio Ground Relay Concept and, in total, studied and ranked 6 relay schemes (3). Analysis of data from staged fault tests and calculations clearly defined the problem and several protection concepts were considered and judged deficient in the light of detection efficiency and economics.

This feasibility study showed that many fallen conductors which would not be detected by phase relays or residually connected ground relays could be detected by other protective relay schemes. The Ratio Ground Relay achieves high impedance fault detection efficiency and economy. These encouraging results justified the development of a prototype Ratio Ground Relay. The following summarizes the development effort which resulted in a prototype relay. The operating characteristic of the prototype is also presented.

Presented at IEEE/PES T&D
Exposition - Minneapolis - 1981

The Data Base

The specification or evaluation of any relay scheme requires a large accurate data base from which relay performance can be determined. In this regard, the digital computer proved to be a valuable tool in the calculation of more than 500 short circuit cases. The development of the fault program included the definition of all significant fault types on PP&L's 4 wire distribution system. Feeder voltages and line currents at various points along the line were calculated for each of the following conditions:

1) Normal conditions
2) One phase to ground fault
3) Two phase to ground fault
4) Three phase to ground fault
5) One phase open, no line grounded
6) One phase open, source bus grounded
7) One phase open, load line grounded
8) One phase open, load bus grounded
9) One phase open, source line grounded

Each fault type was imposed at various points along the feeder, forming a data base to evaluate all relay schemes.

Distribution Feeders

Six distribution circuits representative of the PP&L distribution system were used in fault studies to calculate quantities for a relay coordination program. Studies were conducted using the six feeders at three load levels and characterize 86% of PP&L's 1200-1300 distribution feeders. The test circuits were chosen as typical samples from three general groups: urban, suburban and rural. Schematic diagrams of each of the feeders and the three load levels tested are shown in Figure 1.

The Elliott Heights and Salisbury feeders are in the suburban group. These lines are 5-10 miles long and serve a varied load density of industrial and residential customers. Loads are between 3 and 7 MVA.

The Freemansburg and Schecksville feeders fall into the rural category being 20 miles or longer and serve light density rural load. Loads vary between 2 and 6 MVA.

The urban class of feeders was represented by the Central Allentown and Sumner lines. Both are short lines, approximately 3-4 miles in length, and serve high density load areas. These lines support between 3 and 7 MVA of load.

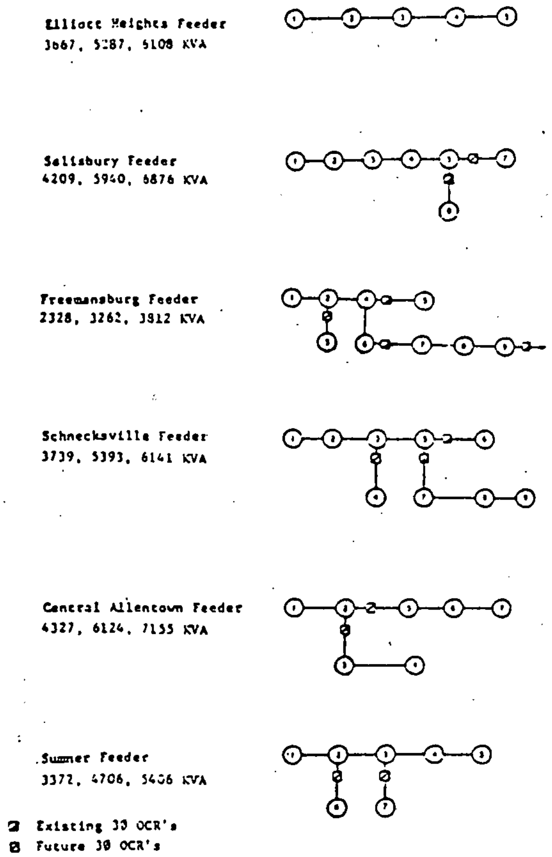

Figure 1
Diagrams of Circuits
Used in Digital Models
At Three Total Loads Shown

RATIO GROUND RELAY SCHEMES STUDIED

A Ratio Ground Relay scheme to be implemented in an electromechanical device is constrained by manufacturing and operating requirements. The selected scheme must be economical, permit construction in a standard relay case size, present a low burden to existing substation current transformers and be simple to apply, test and set. The relay must also be dependable, secure, selective and sensitive. In the particular application of the Ratio Ground Relay, high speed is not a constraint provided reliable operation takes place with proper coordination with existing overcurrent devices.

Using the aforementioned relay characteristics as selection criteria, four Ratio Ground Relay schemes were identified as promising candidates for digital modeling and prototype construction. Each scheme uses the induction disc concept with operating and restraint windings. Contact closing torque in all schemes is produced by residual current ($3I_0$) in the operating winding. Contact opening torque is produced by a combination of phase, positive and/or negative sequence current in the restraint winding. All of the restraint cores shown will produce the desirable constant unbalance ratio trip characteristic. The four Ratio Ground Relay types are:

1) Balanced sequence current difference restraint scheme.

Operating Torque = $K_1N_1^2 \; |3\bar{I}_0|^2$

Restraint Torque = $K_2N_2^2 \; (|\bar{I}_1|^2 - |\bar{I}_2|^2)$

Net Operating Torque = $N \, |3\bar{I}_0|^2 - |\bar{I}_1|^2 + |\bar{I}_2|^2$

$N = K_1N_1^2/K_2N_2^2$

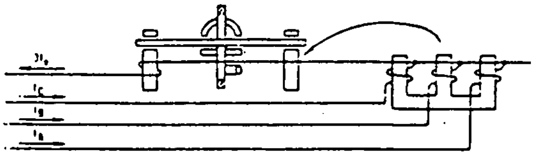

Figure 2
Sequence Current Difference Restraint Element

2) Positive sequence restraint scheme.

Operating Torque = $K_1N_1^2 \; |3\bar{I}_0|^2$

Restraint Torque = $K_2N_2^2 \; |\bar{I}_1|^2$

Net Operating Torque = $N \, |3\bar{I}_0|^2 - |\bar{I}_1|^2$

$N = K_1N_1^2/K_2N_2^2$

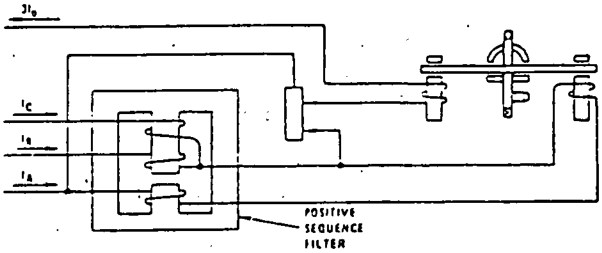

Figure 3
Positive Sequence Restraint Element

3) A+B phase restraint scheme.

Operating Torque = $K_1N_1^2 \; |3\bar{I}_0|^2$

Restraint Torque = $K_2N_2^2 \; |\bar{I}_A + \bar{I}_B|^2$

Net Operating Torque = $N \, |3\bar{I}_0|^2 - |\bar{I}_A + \bar{I}_B|^2$

$N = K_1N_1^2/K_2N_2^2$

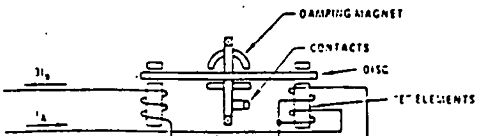

Figure 4
A+B Phase Restraint Element

4) A+B+C phase restraint scheme.

$$\text{Operating Torque} = K_1N_1{}^2 \, |3\bar{I}_0|^2$$

$$\text{Restraint Torque} = K_2N_2{}^2 \, (|\bar{I}_A|^2 + |\bar{I}_B|^2 + |\bar{I}_C|^2)$$

$$\text{Net Operating Torque} = N \, |3\bar{I}_0|^2 - (|\bar{I}_A|^2 + |\bar{I}_B|^2 + |\bar{I}_C|^2)$$

$$N = K_1N_1{}^2/K_2N_2{}^2$$

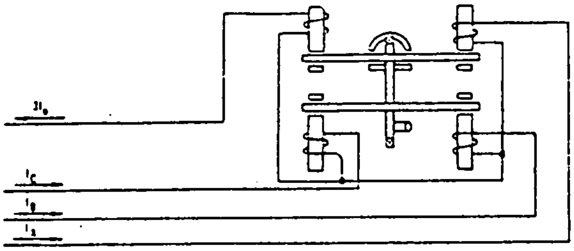

Figure 5
A+B+C Phase Restraint Element

To obtain operating times for various fault conditions from the relay models above, a time overcurrent curve approximation was used. The Net Operating Torque calculated for each relay model was used in a polynomial expression representing an overcurrent relay curve to obtain an operating time. The calculated operating time was then multiplied by a constant time delay multiplier. Thus, a change in tap setting was simulated by changing N, the turns ratio squared, in the net operating torque equation, and a change in time dial was simulated by a change in the time delay multiplier in the time equation.

ANACOM III FEEDER SIMULATION

To determine the effect of fault impedance on system fault quantities a study was performed using the Westinghouse ANACOM III analog computer. A parametric evaluation was completed with variations in fault type, fault impedance, fault location and load level. Several cases which simulated a blown tap fuse were also examined. All cases modeled faults on the Salisbury feeder, which represents a typical PP&L 12.47 KV, three phase, 4 wire distribution feeder.

The actual line, transformer, and load impedances were scaled to appropriate levels and a three-phase model was constructed using precision resistors, inductors, capacitors, and transformers. With this model, a fault type with fault resistance could be analyzed by actually faulting the system through a resistance. The current and voltage magnitude and relative angle between phases was then measured and recorded at locations of interest on the feeder. A fault impedance as represented by a resistance corresponding to 0, 2, 5, 10, 20, 50, and 700 ohms on the actual distribution circuit was inserted in the model for various one phase to ground and broken conductor fallen wire faults. Pure open circuit or broken conductor faults, as well as five blown single phase tap fuses, were also examined.

Substation current magnitude and phase angle data was then entered into a computer algorithm which calculated symmetrical component quantities and checked if conditions were present to trip each of the four Ratio Ground Relay types. The algorithm used the data to provide insight into relay settings and performance for the varied fault resistance. All four Ratio Ground Relay Schemes were found to be almost insensitive to fault resistance for fallen conductors with the load side down as shown in Table I. The backfeed through the grounded wye delta distribution transformers adds to the circuit unbalance and aids the relay for fallen conductors with the load side down. The Ratio Ground Relay detected all one phase to ground and source side down broken conductor faults examined when fault resistance was between 0 and approximately 10 ohms. An impedance of approximately 15 ohms represents full load impedance for a 12.47 kV feeder loaded to 10 MVA.

Fault Resistance (OHMS)	No. Cases Examined	No. RGR Operations
0	6	6
2	6	6
5	6	6
10	6	6
20	2	2
50	6	6
700	5	4

Table I – RGR Operations for Broken Conductor Load Side Down With Fault Resistance

At high sensitivities, all four Ratio Ground Relay schemes performed identically for the faults examined. Lower sensitivities were not examined using analog data. Analog studies provided data which verified and complemented digital studies performed modeling the Ratio Ground Relays.

DIGITAL MODELING

A Digital Fault Calculation Program provided voltage and current data for each of nine fault conditions on six feeders at three load levels. Each fault was imposed at approximately six locations spaced over the entire feeder. Digital studies assumed bolted faults when a ground contact occurred.

A Relay Coordination Program was developed to determine the operating characteristic of each of the four Ratio Ground Relay schemes. Correct operation of the Ratio Ground Relay is based on a comparison of Ratio Ground Relay and overcurrent relay operating times in light of specific coordination criteria for each fault type. The following Ratio Ground Relay (RGR) operation was interpreted by the program as a correct coordination:

i) Fault Type 1 (normal conditions)

- RGR did not operate.

ii) Fault Type 2 (1Ø-GND) or 3 (2Ø-GND) – line continuous

- RGR operated and did not overreach any overcurrent devices.

iii) Fault Type 4 (3Ø-GND) – line continuous

- RGR did not operate.

iv) Fault Type 5 through 9 (open phase faults)

- RGR operated as backup to phase overcurrent devices.
- If phase overcurrent devices did not operate, RGR must operate.

Specification of tap settings for the Ratio Ground Relay required an examination of normal load unbalance on each feeder. Tripping the feeder on an unbalance because of a blown single phase tap fuse was deemed undesirable. Therefore, the unbalance settings allowed normal load unbalance with the tap fuse blown that created the worst circuit unbalance without allowing a false trip of the Ratio Ground Relay. Fault program results of the two worst case blown fuses for each feeder are shown in Table II. Using this data as a basis, two taps were chosen to provide operation on a circuit unbalance ($3I_0/I_1$) of 0.5 and 1.0. Higher sensitivities result on feeders that have a large number of grounded wye-delta transformers in relation to the total KVA of the transformers connected to the circuit.

Feeder	Circuit Unbalance	Tap Setting
Salisbury	0.40 0.39	0.5
Schnecksville	0.45 0.57	1.0
Freemansburg	0.66 0.75	1.0
Elliot Heights	0.23 0.30	0.5
Sumner	0.64 0.39	1.0
Central Allentown	0.26 0.26	0.5

Table II – Circuit Unbalance ($3I_0/I_1$) Resulting From Two Worst Case Blown Fuses

Tables III and IV below summarize the performance of each Ratio Ground Relay scheme for two tap settings based on approximately 550 open phase faults examined. Using the high sensitivity tap, approximately 83% of the open phase fault cases examined were detected with any one of the Ratio Ground Relay restraint elements. Table IV shows that a Ratio Ground Relay with $|\bar{I}_1|^2 - |\bar{I}_2|^2$ restraint or $|\bar{I}_1|^2$ restraint detects a slightly higher percentage of the open conductor faults examined.

Relay Restraint Element	Open Phase	Open Phase Load Side Gnd.	Open Phase Supply Side Gnd.	Avg.
$\lvert\bar{I}_a + \bar{I}_b\rvert^2$	71%	100%	80%	84%
$\lvert\bar{I}_a\rvert^2 + \lvert\bar{I}_b\rvert^2 + \lvert\bar{I}_c\rvert^2$	75%	99%	80%	85%
$\lvert\bar{I}_1\rvert^2 - \lvert\bar{I}_2\rvert^2$	66%	100%	80%	82%
$\lvert\bar{I}_1\rvert^2$	70%	100%	80%	83%

Table III – Ratio Ground Relay Performance Summary 0.5 Unbalance ($3I_0/I_1$) Setting

Relay Restraint Element	Open Phase	Load Side Gnd.	Supply Side Gnd.	Avg.
$\lvert\bar{I}_a + \bar{I}_b\rvert^2$	17%	38%	32%	29%
$\lvert\bar{I}_a\rvert^2 + \lvert\bar{I}_b\rvert^2 + \lvert\bar{I}_c\rvert^2$	14%	73%	31%	29%
$\lvert\bar{I}_1\rvert^2 - \lvert\bar{I}_2\rvert^2$	4%	98%	23%	42%
$\lvert\bar{I}_1\rvert^2$	11%	96%	26%	44%

Table IV – Ratio Ground Relay Performance Summary 1.0 Unbalance ($3I_0/I_1$) Setting

With manufacturing and actual operating considerations in mind, the $|\bar{I}_1|^2 - |\bar{I}_2|^2$ restraint element coupled with a $|3\bar{I}_0|^2$ operating element on a single induction disc was chosen for prototype construction. The other schemes were rejected at this time since their construction would result in larger case size, higher cost, multiple cores or filters, and reduced sensitivity. The device is described and will be applied as shown in the following section.

THE PROTOTYPE RELAY

The prototype Ratio Ground Relay is an electromechanical induction disc unit with an operating and restraint element. The relay is constructed, as shown in Figure 6, to be installed in existing distribution substation switchgear. The relay will be driven by existing phase current transformers and will not require any additional substation equipment. Figure 7 shows the actual prototype which will be installed in a standard directional overcurrent relay case.

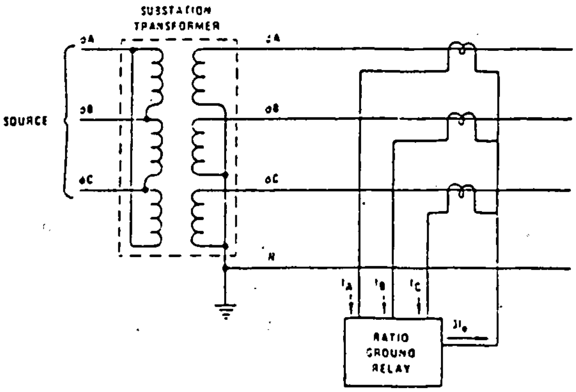

Figure 5 – Installation Diagram of Ratio Ground Relay in Distribution Substation

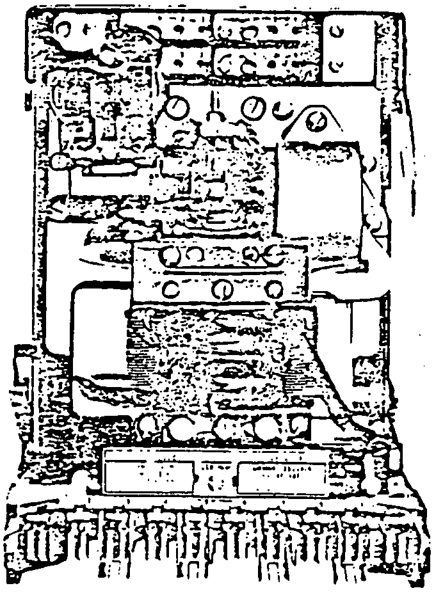

Figure 7 – Prototype Ratio Ground Relay

While the circuit unbalance will determine whether or not the relay will trip, the actual magnitude of the net operating torque on the induction disc will determine the relay operating time. Higher magnitudes of zero sequence current will result in faster tripping times for a constant unbalance. For this reason the relay operating characteristic must be described by a family of time overcurrent curves for each tap setting. A conventional time dial is also provided, allowing further tripping time adjustment.

Normally, feeder unbalance is described in terms of the ratio of zero sequence current to positive sequence current expressed as a percent. However, since the Ratio Ground Relay uses $|\bar{I}_1|^2 - |\bar{I}_2|^2$ as a restraint element, a new method of describing a circuit unbalance became quite desirable. Referring to Figure 8, the phasor representation of feeder currents during faulted conditions can be viewed as consisting of two currents. A current I, in the unfaulted phases due to load and a current RI in the remaining phase due to the combined effect of load and the fault.

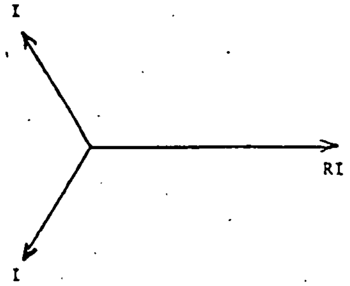

Figure 8 – Feeder Unbalance Representation

Note R can be greater than one (1Ø gnd fault) or R can be less than one (fallen conductor). The actual relay characteristic is as shown in Figure 9.

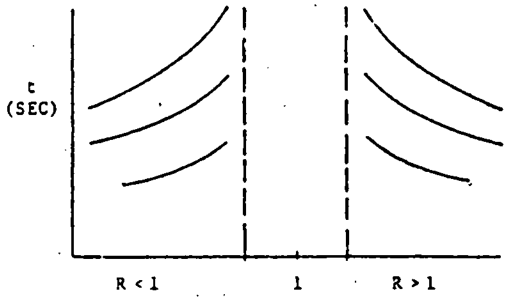

Figure 9 – Typical Ratio Ground Relay Characteristic

Space limitations within the relay case allowed a tap block with three settings corresponding to an unbalance $(3I_0/I_1)$ of 0.5, 0.75 and 1.0. The prototype has a minimum tripping time of approximately 1.5 seconds with a time dial to provide longer operating times should it be necessary for coordination purposes. This will allow application of the relay to a wide variety of four wire distribution feeders.

Conclusions

Four possible Ratio Ground Relay schemes were modeled using digital and analog data to determine design parameters for prototype construction. Three tap settings were determined to be adequate for the six Pennsylvania Power and Light feeders examined, representing 86% of the PP&L distribution system. A prototype relay based on these characteristics was designed and built. Bench tests resulted in a family of time curves for the prototype relay that will allow proper coordination of the Ratio Ground Relay with existing phase overcurrent relays and oil circuit reclosers.

The Ratio Ground Relay is the result of years of effort on behalf of PP&L and Westinghouse, aimed at better detecting the fallen distribution conductor on three phase distribution feeders. The relay has an operating element responsive to zero sequence current and a restraining element responsive to load level. This results in a pick up value that varies with load level which will allow the detection of many broken conductors and high impedance faults. When installed on the feeders at PP&L, data indicates that approximately 80-85% of the fallen conductors on the three-phase feeder should be detected.

Staged fault tests using the prototype on a PP&L distribution feeder are planned. Long-term monitoring of the performance of six prototype devices on six PP&L feeders is also planned. This will yield valuable field data on the application and performance of the Ratio Ground Relay. The performance of the Ratio Ground Relay on other types of utility distribution systems is also being investigated.

ACKNOWLEDGEMENT

This paper is a summary of a Research and Development Program sponsored by the Pennsylvania Power and Light Company and completed jointly by Westinghouse and PP&L. The authors wish to express their gratitude to PP&L's Distribution Fault Current Interruption Task Force – Mr. Herbert F. Farnsler, and to Mr. John Hagberg for their valuable support and guidance for this work.

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Mr. Bishop joined Westinghouse Electric Corporation 1979 through the Graduate Placement Program where he worked with energy management systems and the Electrotechnology Department at Westinghouse Research Laboratories before joining Advanced Systems Technology. Mr. Bishop has been involved in several studies related to distribution systems and protective relaying. He has investigated the effect of distribution feeder configuration on protective device performance. Mr. Bishop has also been involved in efforts to test protective relay performance on variable frequency industrial drive systems.

Mr. Bishop is an assistant instructor for the Westinghouse Advanced School in Power Systems Engineering and an Engineer-in-Training, New York.

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Mr. Eichler joined Westinghouse AST, Systems Analysis, in 1974 and did extensive work in power system planning. He joined Research and Development, Underground Systems, in 1975 where he developed computer programs for the analysis of SF_6 cable systems and performed cable rating studies. Mr. Eichler spent two years in Saudi Arabia as an engineering consultant to the Arabian-American Oil Company in utility and industrial electrical power systems. In 1978 he joined Development Projects where he was involved in the design of a high voltage/high power testing laboratory and in carbon fiber contamination testing of high voltage insulation. He is now involved in photovoltaic generation and development of advanced relaying concepts.

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Robert E. Lee (Member) graduated from Drexel University with a BSEE in 1961. He completed the PTI Power Technology Course in 1974.

Mr. Lee has been employed by Pennsylvania Power and Light Co. since 1961. He was promoted to Project Engineer (1966) and Senior Project Engineer (1969).

In 1975, he became a Senior Engineer in the Development Section of Distribution with prime responsibilities including:

- Conducting technical and economic evaluations of Remote Automatic Metering, Load and Distribution Line Control Technology.
- Technical involvement and supervision of the PP&L effort to discover a means to Detect High Impedance Faults on Distibution Circuits.
- Industry Advisor for EPRI RP-1285-1, "Detection of High Impedance Faults on Distribution Circuits."
- Technical involvement in the PP&L effort to discover a method to prevent burndown of covered overhead distribution conductors.

Mr. Lee is a Registered Professional Engineer in the Commonwealth of Pennsylvania.

SUMMARY FOR
PERFORMANCE TESTING OF THE RATIO GROUND RELAY ON A FOUR-WIRE DISTRIBUTION FEEDER

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Abstract – Digital fault investigations on six Pennsylvania Power and Light 12 kV distribution feeders led to the development of a prototype Ratio Ground Relay to theoretically provide better detection of broken conductor faults. Further assessment of the relay's performance was provided through analog computer tests followed by staged fault testing on an operating distribution feeder. Performance tests are described and documented. These positive test results provided the incentive to monitor the performance of the Ratio Ground Relay on several PP&L distribution feeders.

The Ratio Ground Relay Concept

The Ratio Ground Relay concept, as implemented in the prototype relay, relies on tripping when the ratio of $3I_0$, zero sequence current, to I_1, positive sequence current exceeds a certain pre-set level. This concept is implemented using an induction disc type relay with two windings. The operating winding produces torque proportional to $/3I_0/^2$ and the restraint winding produces torque proportional to $/I_1/^2 - /I_2/^2$. The two opposing torques produce the ratio trip characteristic desired.

Tests Performed

In addition to normal bench testing performed on the prototype relay, two additional testing methods were utilized. The first involved fault testing using an analog model of an actual Pennsylvania Power and Light feeder. During the fault simulations the performance of the Ratio Ground Relay to the various faults was observed.

The second test involved the installation of a Ratio Ground Relay on an actual feeder with temporary current and potential transformer secondary circuits and observation of relay response to faults on the line. The staged fault testing was performed on a Pennsylvania Power and Light Company 12.47 kV feeder from the Salisbury 66/12.47 kV substation in October, 1981.

The paper documents both test methods. The first section of the paper discusses the ANACOM III testing and the second section the staged fault test. Each section describes the test feeder, the equipment necessary to perform the test, the fault cases examined, and a discussion of the Ratio Ground Relay performance.

Conclusions

The Ratio Ground Relay was tested using simulated fault currents from an analog feeder model and actual feeder currents during a staged fault test. During the ANACOM III tests the Ratio Ground Relay detected pure open phase faults over 70-80 percent of the model feeder depending on load level and shunt capacitance connected to the feeder. Single-line-to-ground faults at the substation through a fault impedance of approximately 55 ohms were detected on the model feeder. Single-line-to-ground fault performance of the Ratio Ground Relay depends on load level, fault location along the feeder, and the ground fault impedance. The performance statistics of the Ratio Ground Relay documented in this paper are based on analog and staged fault tests using a Pennsylvania Power and Light distribution feeder.

The testing permitted during the staged fault tests was restricted due to conditions imposed to maintain service to PP&L customers within normal voltage limits. This was accomplished through circuit modifications. The tests could only be conducted on substation property. Thus, a quite severe test sequence was conducted to observe the operation of the Ratio Ground Relay and a ground overcurrent relay. Single line-to-ground line continuous faults through fault impedances of approximately 90-100 ohms occurred and were detected just outside of the substation fence. Many normally occurring faults would produce similar circuit unbalances that could be detected.

Values of voltage and current observed during the ANACOM III and staged fault testing compared favorably with those obtained from the digital simulations. Performance of new relay schemes can now be economically analyzed without the expense of extensive field testing.

Based on the favorable results of the testing program at Pennsylvania Power and Light, the final step of the development program, installation and monitoring the Ratio Ground Relay under field conditions, is being planned. It will be installed on several PP&L distribution feeders and its performance will be monitored under various conditions.

PERFORMANCE TESTING OF THE RATIO GROUND RELAY ON A FOUR-WIRE DISTRIBUTION FEEDER

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Introduction

Many broken or fallen distribution conductors can result in high impedance faults with current magnitudes of 0 to 100 amperes. Fault currents of this magnitude may be insufficient to cause tripping of many types of protection equipment currently in use on distribution systems. A fallen energized distribution conductor may be a potential hazard if not detected and de-energized.

Pennsylvania Power and Light Company (PP&L) has been involved in research and development efforts in high impedance fault detection since 1973. In 1977, PP&L began a joint study with Westinghouse Advanced Systems Technology to investigate the Ratio Ground Relay concept and assess the feasibility of other relaying schemes (1). The feasibility study revealed that the Ratio Ground Relay might offer improved detection of many fallen conductors that might not be detected by conventional phase or residually connected ground relays. With the help of designers at the Westinghouse Relay Instrument Division, an electromechanical Ratio Ground Relay was constructed which resulted in high impedance fault detection efficiency and economy (2).

The Ratio Ground Relay concept, as implemented in the prototype relay, relies on tripping when the ratio of $3I_0$, zero sequence current, to I_1, positive sequence current exceeds a certain pre-set level. This concept is implemented using an induction disc type relay with two windings. The operating winding produces torque proportional to $/3I_0/^2$ and the restraint winding produces torque proportional to $/I_1/^2 - /I_2/^2$. The two opposing torques produce the ratio trip characteristic desired.

In addition to normal bench testing performed on the prototype relay, two additional testing methods were utilized. The first involved fault testing using an analog model of an actual Pennsylvania Power and Light feeder. During the fault simulations the performance of the Ratio Ground Relay to the various faults was observed.

The second test involved the installation of a Ratio Ground Relay on an actual feeder with temporary current and potential transformer secondary circuits and observation of relay response to faults on the line. The staged fault testing was performed on a Pennsylvania Power and Light Company 12.47 kV feeder from the Salisbury 66/12 kV substation in October, 1981.

This paper documents both test methods. The first section of the paper discusses the ANACOM III testing and the second section the staged fault test. Each section describes the test feeder, the equipment necessary to perform the test, the fault cases examined, and a discussion of the Ratio Ground Relay performance.

Description of Feeder

Although normally used for transient studies, the Westinghouse ANACOM III analog computer was put to use in the testing of the prototype Ratio Ground Relay. Using ANACOM III, an accurate real time model of a distribution feeder including load unbalances and transformer banks, was constructed. Amplifiers were used to transform the analog model "substation" currents to the proper relay amplitude. The system produced simulated fault currents that the Ratio Ground Relay might experience in service on a distribution line.

The actual feeder model used on ANACOM III was assembled based on data collected from the Pennsylvania Power and Light Company Salisbury 38-02 line. An elementary one-line diagram of the feeder is shown in Figure 1. The Salisbury line serves varied load density of light industrial and residential customers. Typical heavy load phase current was approximately 300 amperes corresponding to about 6.5 MVA. Typical light loading on the feeder was approximately 200 amperes corresponding to about 4.3 MVA. The ratio of zero sequence residual current ($3I_0$) to positive sequence current (I_1) current under normal circuit conditions was approximately 20%.

Secondary loads are connected to the 12.47 kV four-wire distribution system at PP&L using several methods. Single phase-to-neutral connected distribution transformers dominate. Large three-phase loads are served with either grounded-wye grounded-wye connected transformers or grounded wye-delta connected banks. The ratio of grounded wye-delta connected load to total feeder load varied between 0.5% and 36.7% on the six feeders in the digital studies. The Salisbury 38-02 line chosen for analog modelling on ANACOM III consisted of approximately 11% grounded wye-delta connected load relative to the total feeder load.

The ANACOM III Model

Line and load impedances were scaled up by a factor of ten and actual line voltage was scaled down by a factor of one hundred. In this manner, the model system was operated with approximately one ampere or less at all times. System faults were imposed by hard wiring the appropriate fault connection and impedance into the model and energizing the system. Equivalent system voltages and currents were obtained by direct measurement and the use of appropriate scaling factors.

The input signals to the relay coils were obtained using current amplifier systems as shown in Figure 2. The input signals to the amplifier systems were provided by the ANACOM III model. Phase currents were measured using transformers that provide one millivolt per milliamp circulated through the window. The amplifier system provided voltage gain sufficient to maintain a constant ratio of the current in the relay to the current in ANACOM III model. In essence, the amplifier system acted as a current transformer but did not reflect impedance into the ANACOM III model. Thus, the measurements were taken with minimum disturbance to the circuit and the relay received current signals representative of those it would experience in an actual installation.

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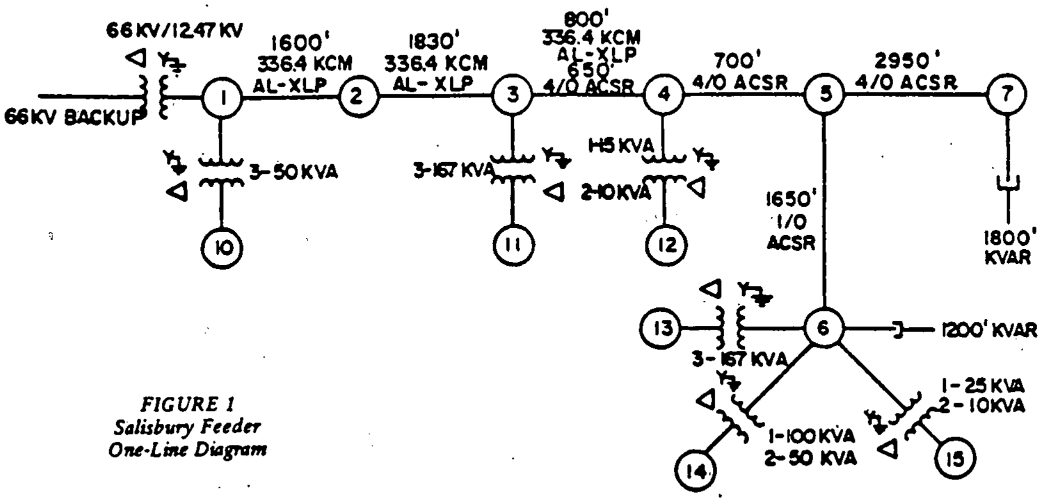


FIGURE 1
Salisbury Feeder
One-Line Diagram

An amplifier system was required on each phase of the ANACOM III feeder model. The zero sequence signal was supplied by an instrument transformer that had all three phase leads passing through its window.

The zero sequence channel also required an amplifier system. In this manner, zero sequence current in the relay was more accurately reproduced since it was independent of any phase shifts that may have occurred across the three-phase amplifier setup.

Fault Cases Examined

The following fault cases were modelled:

a. Normal conditions
b. Line continuous, single-line-to-ground fault
c. Open phase
d. Open phase load line grounded
e. Open phase source line grounded
f. Blown tap fuse simulation

In addition, those faults involving ground utilized several values of fault resistance in order to define the detection capabilities of the prototype relay.

Faults were applied at three locations along the Salisbury feeder. Location 1 is bus number 1 or a fault at the substation. Location 2 is a fault in line section 4 to 5, or approximately 72% of the length of the line from the substation. Location 3 is a fault in line section 5 to 6, which is approximately 75% of the length of the line from the substation. In addition, all fault cases outlined above were imposed during both heavy and light load levels.

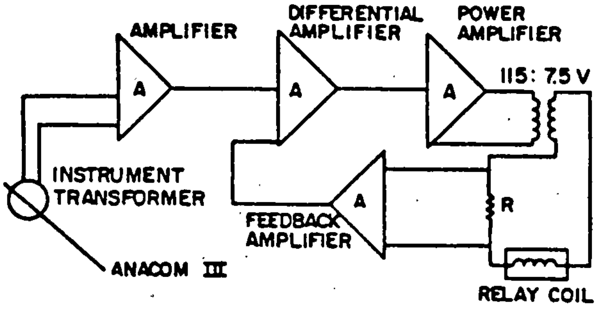


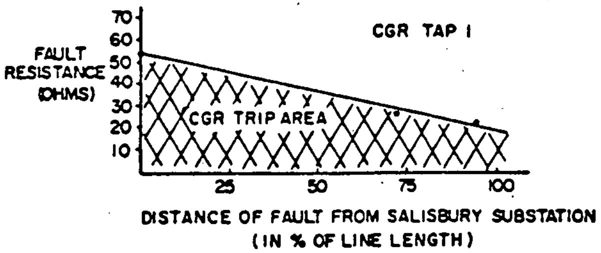
FIGURE 2
Amplifier System

Ratio Ground Relay Performance

The single-line-to-ground fault detection capabilities of the Ratio Ground Relay on the Salisbury feeder model are displayed in Figures 3 and 4. During light load modelling on the ANACOM III computer, the relay detected single-line-to-ground faults of 20 ohms or less over the entire length of the feeder model. Single-line-to-ground faults through higher fault impedances were detected on the model if the fault occurred closer to the substation. As shown in Figure 3, a single-line-to-ground fault through a fault impedance of approximately 55 ohms could be detected on the model feeder under light load conditions using the Ratio Ground Relay.

Figure 4 reveals similar performance of the Ratio Ground Relay under heavy load conditions. Single-line-to-ground faults on the ANACOM III model through a fault impedance of approximately 15 ohms or less were detected by the Ratio Ground Relay. The additional load current during heavy load periods results in a larger restraint torque on the induction disc. Thus, a larger operating torque is required to trip the relay during heavy load periods. Therefore, under heavy load conditions, lower fault impedances are necessary to cause tripping. During heavy loading on the model, a single-line-to-ground fault at the substation through a fault impedance of approximately 40 ohms could be detected by the Ratio Ground Relay.

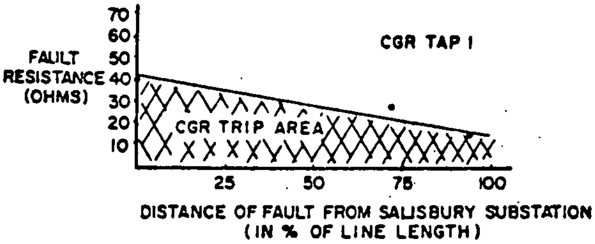
The approximate single-line-to-ground fault that the Ratio Ground Relay might detect can be estimated from the relay characteristic curves published in the Ratio Ground Relay Instruction Leaflet (3). For example, the Salisbury feeder model used during ANACOM III testing had a normal balanced load current of approximately 195 amperes. Utilizing the R/I_L curves for tap 1 of the relay at $I_L = 1.63$ secondary amperes yields an R value equal to approximately



1Ø-GND FAULT PROTECTION
LIGHT LOAD - CAPACITORS OFF

FIGURE 3

1.65 for tripping. Thus, a required current in the faulted phases I_F, (which equals R times I_L, or 1.65 times 1.63) of 2.69 secondary amperes can be calculated. Thus, a single-line-to-ground fault which adds approximately 1.06 secondary amperes to the normal 1.63 present due to load current may be detected by the relay set on tap 1. This corresponds to a fault impedance of approximately 57 ohms. This estimate assumes balanced phase currents at 120 degrees displacement with load and fault current in phase and yields a result almost identical to the largest fault impedance that could be detected at the substation on the ANACOM III model of the PP&L Salisbury feeder. In order to produce the fault current required to produce tripping, a lower fault impedance is required at down-stream locations since the system adds impedance to the fault current path. Hence, the sloping characteristic in Figures 3 and 4.



1Ø-GND FAULT PROTECTION
HEAVY LOAD - CAPACITORS ON

FIGURE 4

The relay performance in detecting open phase faults on the model feeder without any ground contact is shown in Figure 5. The Ratio Ground Relay detected open phase faults over approximately 70-75% of the three-phase feeder simulated on ANACOM III during heavy load conditions. Under light load conditions fault cases were examined with and without the presence of the end of line voltage correction capacitor banks. The effect that the connected capacitance had on the resulting fault current was reflected in the relay performance. The Ratio Ground Relay detected open phase faults over approximately 60-65% of the model feeder during light load conditions with no shunt capacitors connected to the line. With both capacitor banks connected to the model, the Ratio Ground Relay detected open-phase faults over almost 100% of the ANACOM III model feeder during light load conditions.

The Ratio Ground Relay seemed to be almost insensitive to fault impedance for broken conductor faults with the load side faulted to ground. This fault is essentially a pure open-phase fault with the additional effect of fault current flowing in the downed conductor due to the grounded wye-delta transformer banks. This backfeeding effect causes additional unbalancing of the substation currents which aided the Ratio Ground Relay in detecting the open phase load side down faults simulated on ANACOM III. Under light and heavy load conditions open phase load side down faults on the model were detected over 70-75% of the line for fault impedances as high as 700 ohms. The open-phase load side down faults on the remaining portion of the model during light load conditions were detected for fault impedances of 150 ohms or less (100 ohms or less during heavy load period).

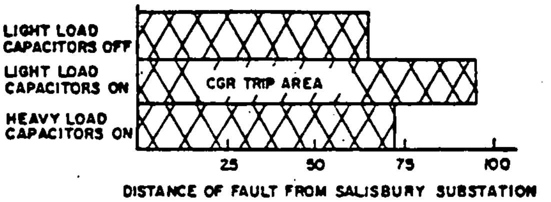
The results of fault modelling using the Salisbury feeder simulated on ANACOM III during broken conductor faults with the source side to ground is shown in Figure 5. For this type of fault, a range of fault impedances will appear to be normal load when viewed from the substation. During heavy load modelling on the ANACOM III, the no-trip area was between approximately 10 and 20 ohms for faults at the substation and increased to approximately 10 and 40 ohms 75% of the distance down the line. Small fault impedances appear to be single-line-to-ground faults and large impedances appear to be open-phase faults. In between these ranges the faults will appear to be normal load.

Staged Fault Test Feeder

The Pennsylvania Power and Light Salisbury 38-02 feeder was one of six 12.47 kV distribution feeders investigated during digital studies and was also modelled on ANACOM III for prototype CGR performance tests. Therefore, it was natural to select the Salisbury line for staged fault testing.

Staged fault testing on an operating line during normal daytime working hours was only permitted if suitable precautions were taken to insure that no customers were adversely effected. Interruption of service was not allowed and service voltage had to be maintained at or above 114 volts.

In order to execute a staged fault test program and insure service to customers, the Salisbury feeder had to be modified. Approximately 45% of the feeder load was transferred from the Salisbury 38-02 line to a neighboring distribution feeder. This line sectionalizing took place close to node 3 in Figure 1. Thus, the grounded wye-delta banks at busses 4 and 6, as well as the capacitor banks at busses 6 and 7, were transferred to another line. Normal load current after all resectionalizing decreased to about 90 amperes from about 170 amperes in the normal feeder configuration at the time of the October tests.



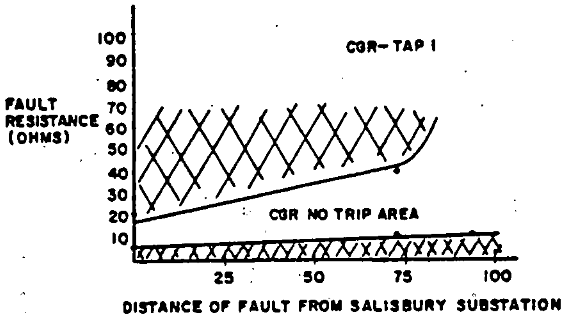
BROKEN PHASE FAULT PROTECTION
CGR TAP I

FIGURE 5

Based on calculations utilizing the Distribution Fault Calculating Program (1) developed by PP&L, two 750-kVA grounded wye-delta transformer banks were installed on the test line. These transformers helped support load side phase voltage during the open-phase fault tests. A 600-kVAR single-phase capacitor bank was also installed on the phase that was opened during the test. In this manner all tests could be executed without degrading customer service voltage. A one-line diagram of the test feeder is shown in Figure 7.

The Salisbury feeder substation has approximately 14,500 amperes available for a bolted single-line-to-ground fault. Although no bolted faults were expected, provision had to be made to add external impedance in the fault path. The additional impedance was provided by a fault current limiter constructed at the test site. A one-line diagram of the fault current limiter is shown in Figure 8. The fault path to ground was thus made up of: a 100 K fuse link, two single-phase transformers, 2700 feet of 1/4 inch galvanized steel guy wire, two single-phase transformers, and a length of 336.4 KcMil aluminum conductor for faulting to the ground surface. Utilizing the fault current limiting equipment, the calculated bolted-ground fault current was 250 amperes. The apparatus was constructed to allow connection of the faulted conductor directly to the feeder through a fused cutout in order to bypass the current limiter. The current limiter was only used for a few calibration tests, but the circuit provided the current limiting security needed to begin the staged fault tests.

Current and voltage transformers were installed for measurement purposes during the test. Figure 9 shows a general installation diagram for these transformers. Current transformers had ratios of 600:5, and potential transformers had ratios of 7200:120. On the source or substation side of the fault location Va, Vb, Vc, Ia, Ib, and Ic were monitored. On the load side of the fault location Va, Vb, Vc, Ia, Ib, Ic and I neutral were monitored. A 600:5 current transformer was also installed on the 336.4 KcMil conductor in the ground fault path to measure the ground fault current. Single-phase switching allowed open-phase faults, single-line-to-ground faults, or combinations.



BROKEN PHASE FAULT PROTECTION
WITH SOURCE SIDE DOWN
HEAVY LOAD– CAPACITORS ON

FIGURE 6

Potential and current transformer secondary wiring was brought down the poles and into the substation in underground conduit. Each of the phase CT secondary wires, as well as the $3I_0$ residual lead, were monitored using a 1.0 volt/ampere instrument transformer. The output of each of the instrument transformers was connected to one channel of a Honeywell visicorder via coaxial cable. The source side CTs provided current signals for the Ratio Ground Relay and the ground overcurrent relay. Voltage probes connected to the six-phase voltage signals provided input signals for six visicorder channels. A small DC voltage across the relay trip contacts was also monitored on a visicorder channel. A collapse in voltage indicated closed contacts. In this manner, relay operation during a fault event was recorded simultaneously with the fault currents and voltages.

TABLE 1
Test Summary-Tie Breaker Closed

	Ground Overcurrent Relay	Ratio Ground Relay
Normal conditions'		
Line continuous ground faults		
Covered to grass		
Covered to gravel		
Covered to asphalt		
Covered to concrete (expansion joint)		Moving
Covered to concrete		
Bare to grass		Moving
Bare to gravel		Moving
Bare to asphalt		
Bare to tree		
Phase A open - source side faults		
No shunt fault	Trip	Trip
Bare to tree	Trip	Trip
Covered to grass	Trip	Trip
Covered to gravel	Trip	Trip
Covered to asphalt	Trip	Trip
Covered to concrete	Trip	Trip
Bare to grass	Trip	Trip
Bare to asphalt	Trip	Trip
Bare to concrete	Trip	Trip

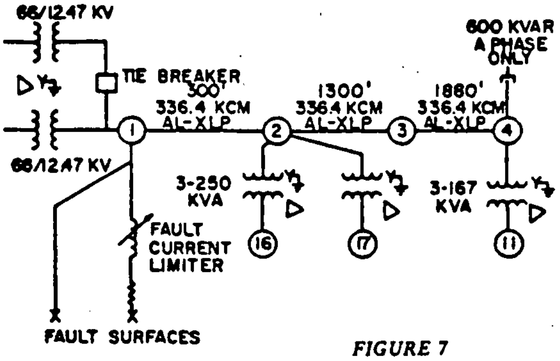


FIGURE 7
Test Feeder One-Line Diagram

Staged Fault Test Cases

Four ground-fault surfaces were used during the tests. A concrete pad, an asphalt pad and a gravel patch were installed as fault surfaces along with the grassy area surrounding the substation. Tests were performed in the Allentown, PA area in October. Both test days were sunny and the temperature was approximately 70-75 degrees Fahrenheit. It had been approximately one week since a rainfall. All faults were within approximately 30 yards of the substation fence.

The Salisbury substation is served by two 66/12.47-kV transformers which can be paralled on the 12.47-kV side through a tie breaker. During the first day of testing, the tie breaker remained closed and on the second day several tests were repeated with the tie breaker open.

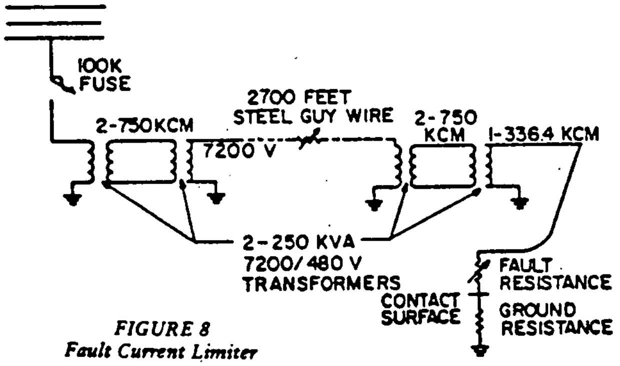


FIGURE 8
Fault Current Limiter

TABLE 2
Test Summary-Tie Breaker Open

	Ground Overcurrent Relay	Ratio Ground Relay
Line continuous ground faults		
Bare to grass		Moving
Bare to gravel		Moving
Bare to asphalt		
Bare to wet asphalt		
Bare to concrete		Moving
Bare to grass		
Covered to gravel		
Covered to asphalt		
Covered to concrete		Moving
Phase A Open - source side faults		
No shunt fault	Trip	Trip
Covered to grass	Trip	Trip
Covered in concrete	Trip	Trip
Bare to grass	Trip	Trip
Bare to concrete (25 ft.)		Moving
Line continuous		
50 ft. bare to grass		Trip

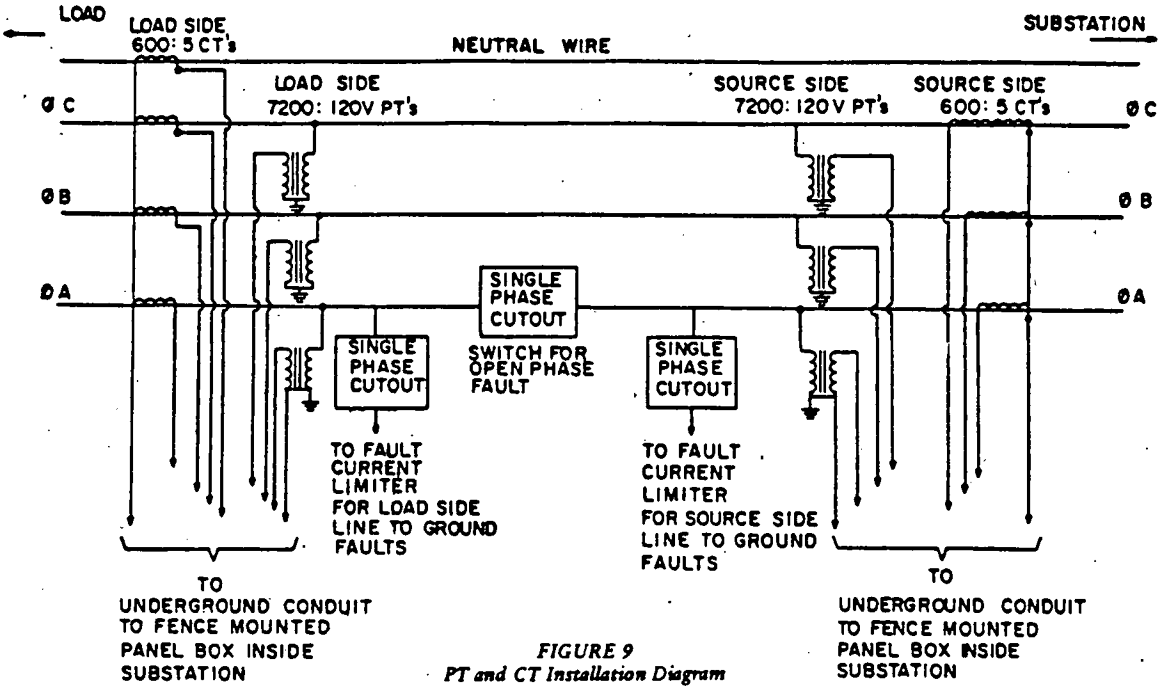


FIGURE 9
PT and CT Installation Diagram

Single line-to-ground faults, as shown in Tables 1 and 2, were staged to the four surfaces and a nearby tree using both covered and bare 336.4 KcMil aluminum conductor. In order to minimize the chance of any customer interruption due to the test, faults were left on the system for approximately 30 seconds. In some cases this was not a sufficient amount of time to allow the Ratio Ground Relay to completely close its contacts. In the cases where the contacts were closing, but the fault was removed before the relay timed out, a note was made that the contacts were moving. Trips versus moving contacts are delineated in Tables 1 and 2.

Fault Currents Observed

Table 3 shows the calculated approximate fault impedance values for each of the fault surfaces used during the test. The average fault current for each surface is shown with the number of cases used in the calculation of the average.

The asphalt pad presented an infinite fault impedance to both the bare and covered conductors. The asphalt pad was even coated with several gallons of water for one of the tests and no measurable fault current was present in the faulted conductor.

The tree also presented an extremely high impedance to the faulted conductor. The covered conductor to the tree represented an infinite fault impedance with no perceptible fault current. The bare conductor in the tree resulted in a very small fault current which was estimated to be 1.2 amperes (approximately 6,000 ohms).

The bare conductor faults to grass, gravel and concrete produced a fault current of approximately 90 amperes for all three surfaces. This indicates a fault impedance of approximately 80 ohms for each of the three surfaces.

The 150 mil cross-linked polyethylene covering on the conductor tended to increase the fault impedance as shown in Table 3. The resulting fault impedance for a covered conductor in contact with gravel or concrete was approximately 125 ohms compared to about 80 ohms for bare conductor. The covering increased the fault impedance for a contact with grass substantially, yielding a value of about 270 ohms covered versus 80 ohms bare.

TABLE 3
Approximate Fault Impedances

Conductor and Surface	No. of Cases	Avg. Fault Current	Avg. Fault Impedance
Covered to grass	4	26 amps	270 ohms
Covered to gravel	3	55 amps	130 ohms
Covered to asphalt	3	0	-
Covered to concrete	4	61 amps	120 ohms
Covered to tree	1	0	-
Bare to grass	4	86 amps	80 ohms
Bare to gravel	3	87 amps	80 ohms
Bare to asphalt	4	0	-
Bare to concrete	3	97 amps	75 ohms
Bare to tree	1	1.2 amps	6000 ohms

Relay Performance

A Ratio Ground Relay set on tap 1 (adjusted for a 0.5 ampere sensitivity) (3) and a ground overcurrent relay set at 1.2 secondary amperes pick-up were installed in the temporary CT circuits mounted on the source side of the fault location. In this way, both relays received identical phase and/or residual current.

The normal load current on the first day of testing was approximately 105 primary amperes with approximately 28 amperes of residual ($3I_0$) current. The Ratio Ground Relay detected four line continuous single-line-to-ground faults of greater than approximately 80 amperes during the first day of testing. The ground overcurrent relay did not detect any of the single-line-to-ground faults with the line continuous on the first day of testing as $3I_0$ did not exceed approximately 100 amperes during any of these staged faults.

During the second day of the staged fault tests the Ratio Ground Relay again detected four of the single-line-to-ground line continuous faults. It detected ground-fault currents on the test feeder in excess of approximately 70 amperes or a ($3I_0$) residual current in excess of approximately 85 amperes. The ground overcurrent relay did not detect any of the single-line-to-ground line continuous faults on the test feeder on the second day of testing as the maximum $3I_0$ current during these faults was again about 100 amperes.

The pure open-phase fault on both days of the test produced a $3I_0$ current of approximately 250 amperes. An open phase with a source side line-to-ground fault will tend to produce a lower $3I_0$ current because the fault current partially restores the lost load current in the open phase. This was observed during the staged fault test as high fault currents tended to cancel the residual current.

The Ratio Ground Relay detected all of the open-phase source side single-line-to-ground faults conducted during the staged test. The Ratio Ground Relay was also able to detect this type of fault when long sections of conductor contacted ground to produce $3I_0$ values of approximately 136 amperes (25 ft. of bare conductor to concrete) and approximately 180 amperes (50 ft. of bare conductor to grass).

The ground overcurrent relay did not detect the open phase source side line-to-ground fault through 25 ft. of bare conductor to concrete. This fault produced a $3I_0$ of approximately 136 amperes which was below the pick-up value of 144 amperes. The ground overcurrent relay was able to detect all the other open-phase faults during the two days of the test.

The final test on the second day involved approximately 50 ft. of bare conductor in grass with the line continuous. This single-line-to-ground fault produced a fault current of approximately 200 amperes resulting in a ($3I_0$) residual current of about 180 amperes. The fault was left on for approximately 1.25 minutes and the Ratio Ground Relay tripped. In that time period, the ground overcurrent relay did not trip and no disk travel was observed.

Conclusions

The Ratio Ground Relay was tested using simulated fault currents from an analog feeder model and actual feeder currents during a staged fault test. During the ANACOM III tests the Ratio Ground Relay detected pure open phase faults over 70-80 percent of the model feeder depending on load level and shunt capacitance connected to the feeder. Single-line-to-ground faults at the substation through a fault impedance of approximately 55 ohms were detected on the model feeder. Single-line-to-ground fault performance of the Ratio Ground Relay depends on load level, fault location along the feeder, and the ground fault impedance. The performance statistics of the Ratio Ground Relay documented in this paper are based on analog and staged fault tests using a Pennsylvania Power and Light distribution feeder.

The testing permitted during the staged fault tests was restricted due to conditions imposed to maintain service to PP&L customers within normal voltage limits. This was accomplished through circuit modifications. The tests could only be conducted on substation property. Thus, a quite severe test sequence was conducted to observe the operation of the Ratio Ground Relay and a ground overcurrent relay. Single line-to-ground line continuous faults through fault impedances of approximately 90-100 ohms occurred and were detected just outside of the substation fence. Many normally occurring faults would produce similar circuit unbalances that could be detected.

Values of voltage and current observed during the ANACOM III and staged fault testing compared favorably with those obtained from the digital simulations. Performance of new relay schemes can now be economically analyzed without the expense of extensive field testing.

Based on the favorable results of the testing program at Pennsylvania Power and Light, the final step of the development program, installation and monitoring the Ratio Ground Relay under field conditions, is being planned. It will be installed on several PP&L distribution feeders and its performance will be monitored under various conditions.

References

(1) PP&L, Westinghouse - "Improved Relay Schemes for the Detection of Fallen Conductors on Three-Phase, Four-Wire Distribution Circuits," M. Rosado, L. A. Kilar, D. F. Shankle, R. E. Lee, presented at the IEEE/PES 1979 Conference and Exposition on Transmission and Distribution.

(2) PP&L, Westinghouse - "Development and Testing of an Electro-Mechanical Relay to Detect Fallen Distribution Conductors," H. Calhoun, C. H. Eichler, R. E. Lee, M. T. Bishop, presented at the IEEE/PES 1981 Conference and Exposition on Transmission and Distribution.

(3) Westinghouse - "Type CGR Ratio Ground Relay, Installation - Operation - Maintenance," I. L. 41-107, Westinghouse Electric Corporation, Relay Instrument Division, Coral Springs, FL.

Martin T. Bishop (Member) graduated from Rensselaer Polytechnic Institute with BSEPE in 1978 and an MSEPE in 1979. Mr. Bishop joined Westinghouse Electric Corporation in 1979 through the Graduate Placement Program. While on the graduate program he completed assignments with the Energy Management Systems group at the Industry Systems Division and also with the Electrotechnology Department at the Westinghouse Research Laboratories before joining Advanced Systems Technology. Mr Bishop has been involved in several studies related to distribution system and protective relaying. He has also investigated the effect of distribution feeder configuration on protective device performance. Mr. Bishop is an instructor for the Westinghouse Advanced School in Power Systems Engineering and an Engineer-in-Training, New York.

Robert E. Lee (Member) graduated from Drexel University with a BSEE in 1961. He completed the PTI Power Technology Course in 1974. Mr. Lee has been employed by Pennsylvania Power and Light Co. since 1961. He was promoted to Project Engineer (1966) and Senior Project Engineer (1969). In 1975, he became a Senior Engineer in the Development Section of Distribution with prime responsibilities including:

- Conducting technical and economic evaluations of Remote Automatic Metering, Load and Distribution Line Control Technology.
- Technical involvement and supervision of the PP&L effort to discover a means to detect high impedance faults on distribution circuits.
- Industry Advisor for EPRI RP-1285-1, "Detection of High Impedance Faults on Distribution Circuits."
- Technical involvement in the PP&L effort to discover a method to prevent burndown of covered overhead distribution conductors.

  In 1982, Mr. Lee assumed the responsibilities of Supervisor of Distribution Research and Reliability.

Mr. Lee is a Registered Professional Engineer in the Commonwealth of Pennsylvania.

Responses from mines include the following:

Organization	No Response	Negative Response	Referrals
• CECHAR Industrie, France			X
• American Institute of Mechanical Engrs., Iron & Steel Society, U.S.A.		X	
• American Society of Mining Engrs., U.S.A.			X
• American Iron & Steel Institute, U.S.A.		X	
• National Coal Association, U.S.A.		X	
• Bituminous Coal Operations Association, U.S.A.			X
• American Mining Congress, U.S.A.			X To USDOI & USDOL
• Bureau of Mines, U.S. Dept. of Interior, U.S.A.			X To Pittsburgh Research Center
• U.S. Dept. of Labor, Office of Mine Safety & Health, U.S.A.			X To West Virginia Laboratories
• U.S. Dept. of Labor, Research Center of West Virginia, U.S.A.			X To Consolidated Edison Co. of McMurray, PA
• Climax Molybdenum Co., U.S.A.			X To Henderson Mine of Colorado
• Vapor Corporation, U.S.A.		X	

Positive responses were indicated as follows:

- Henderson Mine, Colorado, U.S.A., reported using a BBC-Sécheron DDL device with a BBC feeder breaker. The mine was temporarily shut down after the relay installation for improvements and hence performance was not reported as yet.
- Bureau of Mines, Pittsburgh, Pennsylvania, U.S.A., reported in brief that it has funded low-current fault detection device development but because of conflict on interpretation of liabilities, the project did not get completed satisfactorily.
- Consolidated Coal Company, McMurray, Pennsylvania, U.S.A., provided the following three papers (copies follow): (1) "An Improved System for the Protection of Trolley Wires in Underground Coal Mines," by John F. Burr; (2) "Trolley Wire Protection by Simplified Discriminating Circuit Breaker," by Paice and Conroy; and (3) "Demonstration of the Discriminating Circuit Breaker (DISB)," by M. R. Yenchek. These papers describe major approaches to the detection of low-current faults; however, no information with respect to the cost of such systems was made available to the project.

AN IMPROVED SYSTEM FOR THE PROTECTION OF TROLLEY WIRES IN UNDERGROUND COAL MINES

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ABSTRACT

The Lee Engineering Division of Consolidation Coal Company is in the process of developing an improved system for the protection of trolley wires in underground coal mines. This system will require the continuous transmission of coded radio signals from the mobile vehicles, moving on the tracks, to an antenna wire. The antenna wire will have to be extended over the entire length of trolley wire, protected by a particular power circuit breaker. A receiver located at the circuit breaker and connected to the antenna wire, will determine the total connected horsepower operating from that section of trolley wire. The receiver will then adjust the overcurrent trip setting of that circuit breaker to an appropriate level. The mobile vehicles will also be capable of transmitting an emergency signal which will cause the receiver to trip and lock out the circuit breaker.

INTRODUCTION

The present method used to protect trolley wires in underground coal mines depends on power circuit breakers, each equipped with a series overcurrent relay. However, normal load currents which may exceed 3000 amps on a 300 VDC system are often greater than arcing or high impedence ground fault currents. Therefore, the present method cannot protect against many possible ground faults. Too often undetected ground faults, on DC trolley distribution systems, have resulted in mine fires and loss of lives. The need for an improved system for the protection of trolley wires in underground coal mines is, therefore, obvious.

CERCHAR SYSTEM

The French equivalent of our United States Bureau of Mines, Cerchar, has developed a system which is capable of differentiating between large load currents and small ground fault currents on two conductor DC distribution systems with one conductor grounded. This equipment is manufactured by the French firm of Merlin Gerin and is in use at several French coal mines. The system, shown in figure 1, superimposes a 10 volt, 3500 Hz signal onto the trolley wire. All legitimate loads are tuned so that they will have a relatively high impedance at 3500 Hz. By monitoring the flow of 3500 Hz current, ground faults on the order of 50 to 100 amps can be detected even though normal load currents may be in excess of 2000 amps. The key to the French system is that they are able to tune their legitimate locomotive loads to approximately 600 ohms at 3500 Hz by merely placing capacitors across the motor leads. Lee Engineering field tested this system during the winter of 1972. By placing capacitors across the motor leads, we were able to increase the 3500 Hz impedance of a 50 ton locomotive to only 7 ohms. The reason for this is that there are two significant differences between American and French trolley haulage systems. The first difference is that the French operate their trolley wires at 550 VDC, while we generally use 300 VDC. This means that a French motor will have approximately twice the number of turns of a comparable American motor. Therefore, the self inductance of the French motor will be approximately four times greater than that of the American motor. The second difference is that French locomotives rarely have more than 150 total connected horsepower, while American locomotives may have up to 720 total connected horsepower. The larger American motors have more iron surrounding the windings and, therefore, will have more eddy currents induced into the motor frames. These eddy currents can become large enough to make the coil appear as a transformer with a short circuited secondary. We had special inductors constructed which could increase the 3500 Hz impedance of a 50 ton locomotive to 600 ohms. Each inductor had a 24 inch outer diameter, was 22 inches high and weighed 250 pounds. Field tests, with these inductors, indicated that as many as 6 would be required on a 50 ton locomotive. At this point we decided that the Cerchar system, as manufactured by Merlin Gerin, was not suitable for use in American coal mines. At the present time, Westinghouse Electric Corporation, under a research contract from the United States Bureau of Mines, is developing an electronic active filter which may make a system similar to the Cerchar one practical for use in American coal mines.

RATE-OF-RISE SYSTEMS

A second method capable of differentiating between large load currents and smaller ground fault currents is one that monitors the rate of change of current. Both General Electric and ITE have developed rate-of-rise detection circuits. However, these circuits can only be used in underground coal mines which have a 600 VDC trolley distribution system. The reason that these circuits cannot be used with a 300 VDC trolley system is demonstrated in the following diagrams. Figure 2 shows the current and the rate-of-rise of current plotted as a function of time for a simple LR circuit. The initial rate-of-rise is independent of the circuit resistance and, therefore, the magnitude of the current. The General Electric system uses a level detection circuit to trip the circuit breaker, if the magnitude of di/dt increases above a preselected level. This device has been used on a prototype solid state circuit breaker developed for U.S. Steel and tested at their Maple Creek Mine. The ITE system uses a level detection circuit and a time delay circuit so that it will trip the circuit breaker if the magnitude of di/dt increases above a preselected level for a fixed period of time. If we assume the following parameters for a 600 VDC system; .26 mh per 1000 feet of trolley line and .85 mh for a 50 ton locomotive. Either system should be capable of differentiating between resistance faults over 3000 feet from the breaker and normal loads, even though the load currents may be many times greater than the fault currents. For a 300 VDC system, the inductance of the trolley line will still be .26 mh per 1000 feet, but the inductance of a 50 ton locomotive will be .2 mh. Therefore, on a 300 VDC system, a rate-of-rise detector cannot differentiate between normal loads and resistance faults which are much more than 750 feet from the detector.

REMOTE CONTROL OF CIRCUIT BREAKER OVERLOAD SETTING

At Lee Engineering, we felt that it might be possible to significantly improve the present method of protecting trolley wires in underground coal mines without actually developing a ground fault detection system. We are now in the process of developing a system for remote control of the overload setting of our existing circuit breakers. This system will require the continuous transmission of coded radio signals from the mobile vehicles, moving on the tracks, to an antenna wire. The antenna wire will have to be extended over the entire length of trolley wire, protected by a particular power circuit breaker. A receiver located at the circuit breaker and connected to the antenna wire, will determine the total connected horsepower operating from that section of trolley wire. The receiver will then adjust the overcurrent trip setting of that circuit breaker to an appropriate level. The mobile vehicles will also be capable of transmitting an emergency signal which will cause the receiver to trip and lock out the circuit breaker. The system is made up of the following items:

1. Shunt Trip Conversion Kit
2. Transmitter
3. Transmitting Antenna
4. Receiving Antenna
5. Receiver

<u>Shunt Trip Conversion Kit</u> - As described above, the present method used to protect trolley wires, in underground coal mines, depends on power circuit breakers each equipped with a series overcurrent relay. If we now want to vary the overload setting, of a circuit breaker from a remote transmitter, the series trip circuit breaker must be converted to a shunt trip device. ITE has developed a Model 76 solid state overcurrent relay which can be used for this purpose. The relay is approximately 9" x 7" x 5" and, as shown in figure #3, is powered from a 120 VAC source. The unit, when used with a shunt, can provide instantaneous protection at any one of ten preselected levels. These levels are 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mV. When the preselected level is exceeded, a set of normally closed contacts is opened to interrupt the current flowing to the circuit breaker holding coil. These contacts are rated 1 amp inductive at 325 VDC.

<u>Transmitter</u> - To this date, our work at Lee Engineering with radio signals, in underground coal mines, has indicated that only two frequency bands are of practical interest. Equipment, operating between 150 MHz and 450 MHz, has demonstrated very good performance for line-of-sight wireless communication. In fact, some work seems to show that frequencies as high as 1 GHz may be superior for wireless line-of-sight communication. However, 1 GHz equipment is not presently commercially available. Units operating between 500 KHz and 1 MHz have shown very good results for wide area communication, especially if a carrier wire is available. Unfortunately, this is the standard radio broadcast band in the United States. Therefore, we have used the band between 100 KHz and 500 KHz for wide area coverage with very satisfactory results. This system requires that a coded radio signal be continuously transmitted by the mobile equipment and that this signal be received at two stationary locations which will be approximately 5000 feet apart. Therefore, we chose to operate the transmitter in the 100 KHz to 500 KHz frequency band. The transmitter can have its base frequency set anywhere in this band by exchanging plug-in crystals. Once the base frequency has been selected, the actual frequency of a transmitter can be moved from the base frequency, in 500 Hz steps, as much as 30 KHz. This is done with plug-in jumpers. The transmitters are powered from a 12 VDC supply and are keyed on from a dead-man switch. Each transmitter can deliver up to 25 watts into the 10 ohm transmitting antenna.

<u>Transmitting Antenna</u> - In order to cover the entire range of the transmitter, three transmitting antennas had to be designed. All of the antennas are approximately 18" long, 6" high and are enclosed in a 1" plastic tube which is sealed. The first antenna operates between 135 KHz and 200 KHz, it consists of 18 turns of number 18 AWG wire in series with 3 capacitors. The capacitors can be tapped to provide reson-

ant tuning in this frequency band. The other antennas are of similar construction with the second antenna operating from 200 KHz to 350 KHz, and the third operating from 350 KHz to 500 KHz. When mounting the transmitting antenna on the vehicle, it is important that it be placed at least 5" from any metal surface.

Receiving Antenna - The receiving antenna, shown in figure #4, is a number 12 AWG, 30% copper, conductor with 600 volt PVC insulation. We have usually supported the antenna wire with plastic J hooks, hung from the roof, on the side of the entry opposite the trolley wire. There is no minimum clearance which must be maintained between the receiving antenna and the surrounding rib or roof. We have operated this system with the receiving antenna in contact with both the rib and the roof. The antenna must be installed throughout the entire block of trolley wire, protected by two adjacent circuit breakers. In fact, the wire must be extended beyond the block approximately 250 feet to allow for the mechanical delay in adjusting the overload setting of the circuit breaker. This will mean that for approximately 500 feet the receiving antenna, of one block, will be parallel to the receiving antenna of the adjacent block. We have found that as long as the wires are at least 2 feet apart, signals induced in one antenna (from the adjacent antenna) will be negligible. The antennas are terminated to ground at each end thru a 250 ohm resistor.

Receiver - A receiver, as shown in figure #5, is located at each circuit breaker protecting a length of trolley wire and controls the overload setting of that particular breaker. There is the obvious possibility of using only one receiver for a block of trolley wire and having it control both circuit breakers. However, we felt that the initial field testing would be much simpler with one receiver for each breaker. The receiver can have its base frequency set anywhere from 100 KHz to 500 KHz with plug-in crystals. It then scans, at 500 Hz intervals, a 30 KHz band, starting with the base frequency. The scan rate is 16 ms per channel or approximately one complete scan per second. Each channel is weighted, at the receiver, with a multiplying factor proportional to the full load current of the vehicle identified by that channel. At the end of each scan, the receiver will sum the weighted output of each channel and decode this to one of eight possible circuit breaker overload settings. This output then goes to a logic circuit which will allow the circuit breaker overload setting to increase immediately, but will require a four second time delay before decreasing the circuit breaker overload setting. An additional feature of this system is the capabiltiy of every transmitter to transmit the base frequency. Therefore, a push button which initiates transmission of the base frequency can be installed on each vehicle. The receivers can then be programmed to interpret the base frequency as an emergency signal which would require that the breaker be tripped and locked out.

PROJECT STATUS

Prototypes of the shunt trip conversion kit, transmitter, transmitting antenna, receiving antenna and the receiver were successfully field tested at the #2 Mine of our Blacksville Division for approximately six weeks. We expect to have production models of this equipment installed and operating at the Shoemaker Mine of our Ohio Valley Division this summer.

CONCLUSION

Consolidation Coal Company feels that a system which can reliably distinguish between large normal load currents and smaller ground fault currents would represent the ideal solution to the problem of protecting trolley wires in underground coal mines. However, our work at Lee Engineering has shown that there are very serious problems in trying to apply known methods of ground fault detection to trolley wires in American underground coal mines. Therefore, we have developed a system which represents a significant improvement in the protection of trolley wires and could possibly eliminate the need for a ground fault detection system. We feel that if a system of this type were in operation, it could have prevented the vast majority of mine fires which have been started by ground faults on trolley distribution systems.

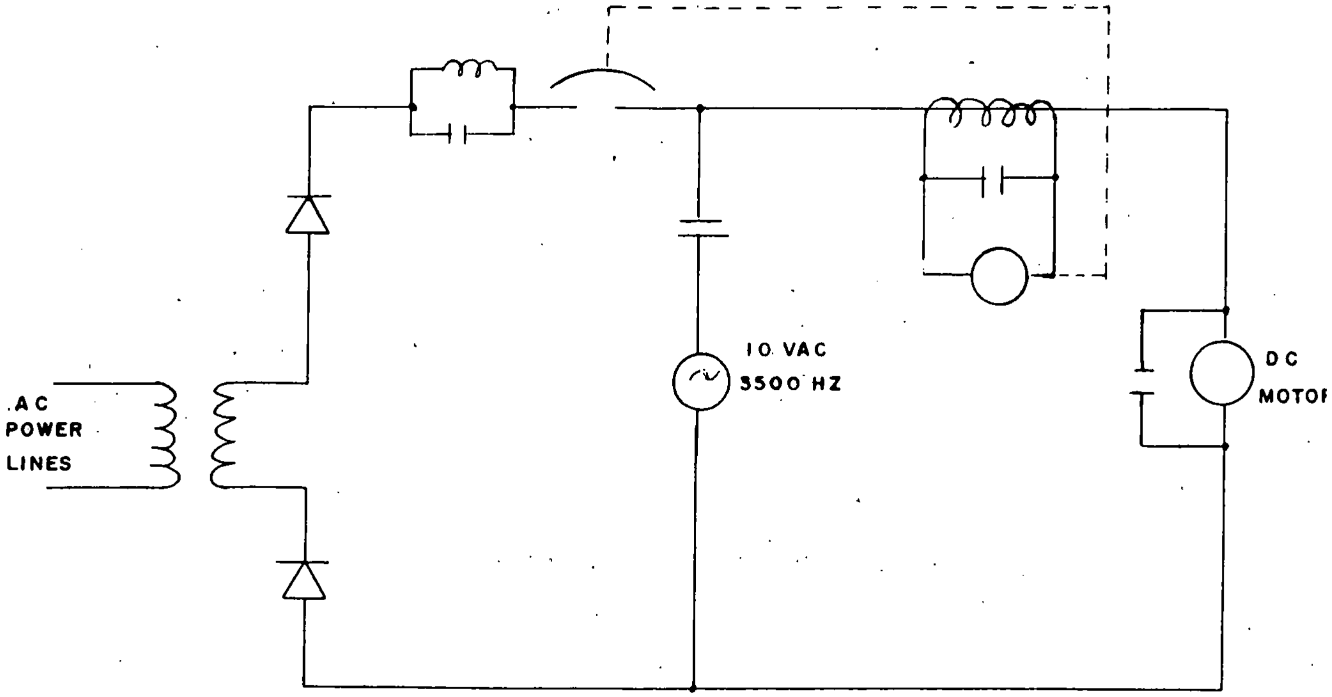

Figure 1

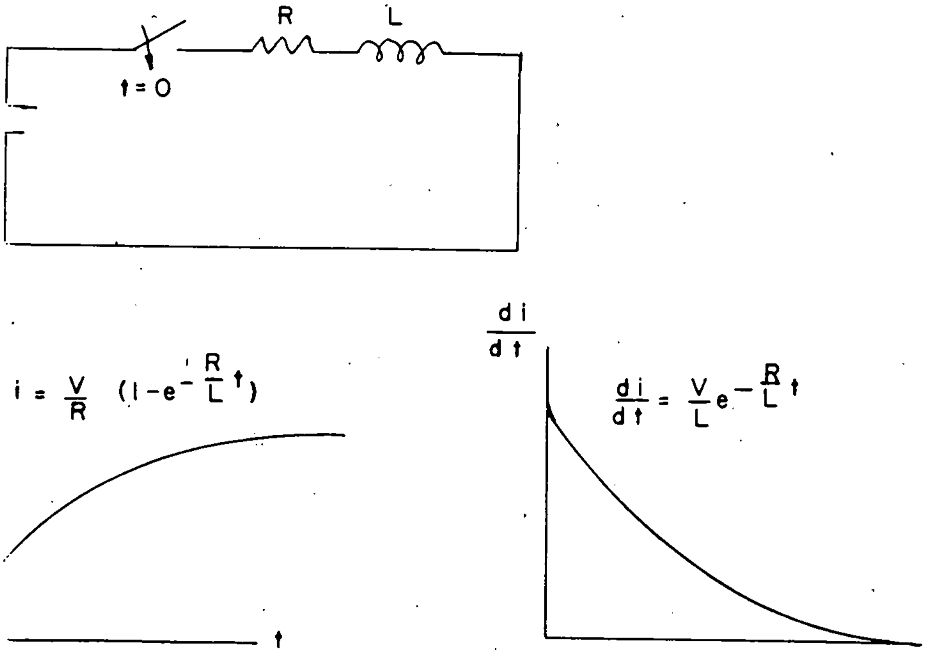

Figure 2

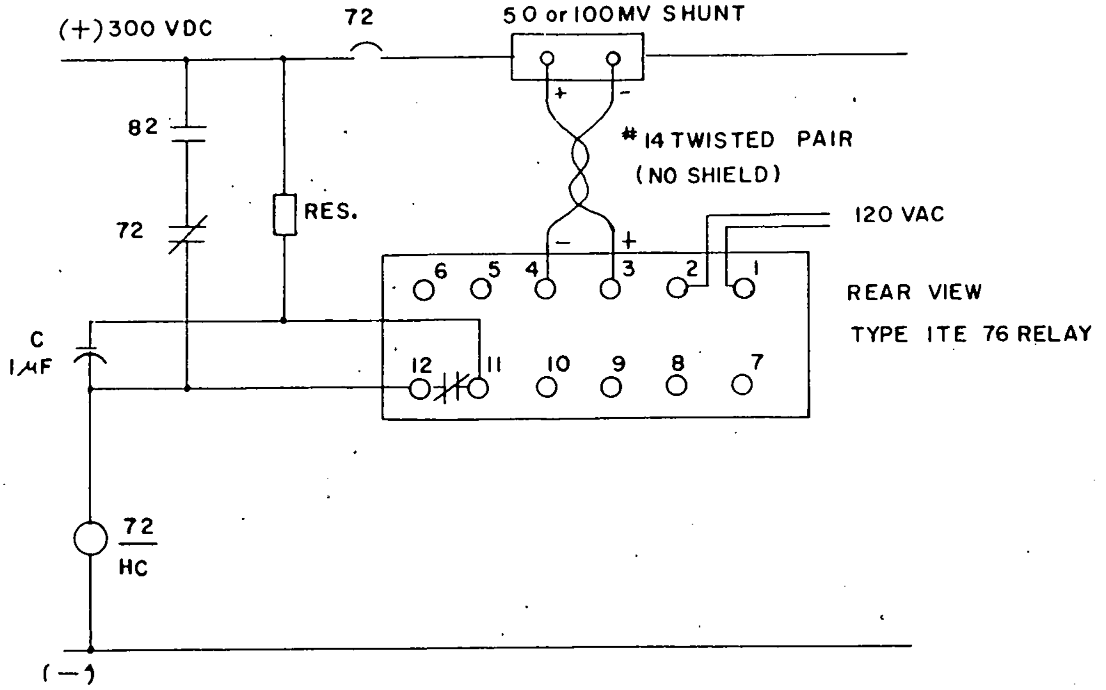

Figure 3

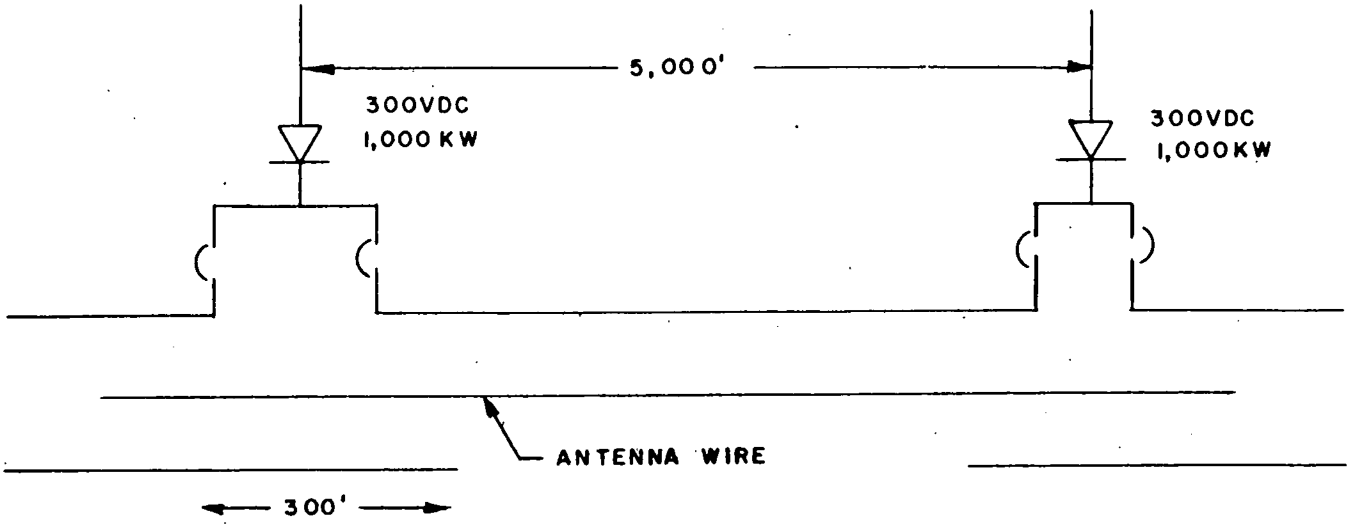

Figure 4

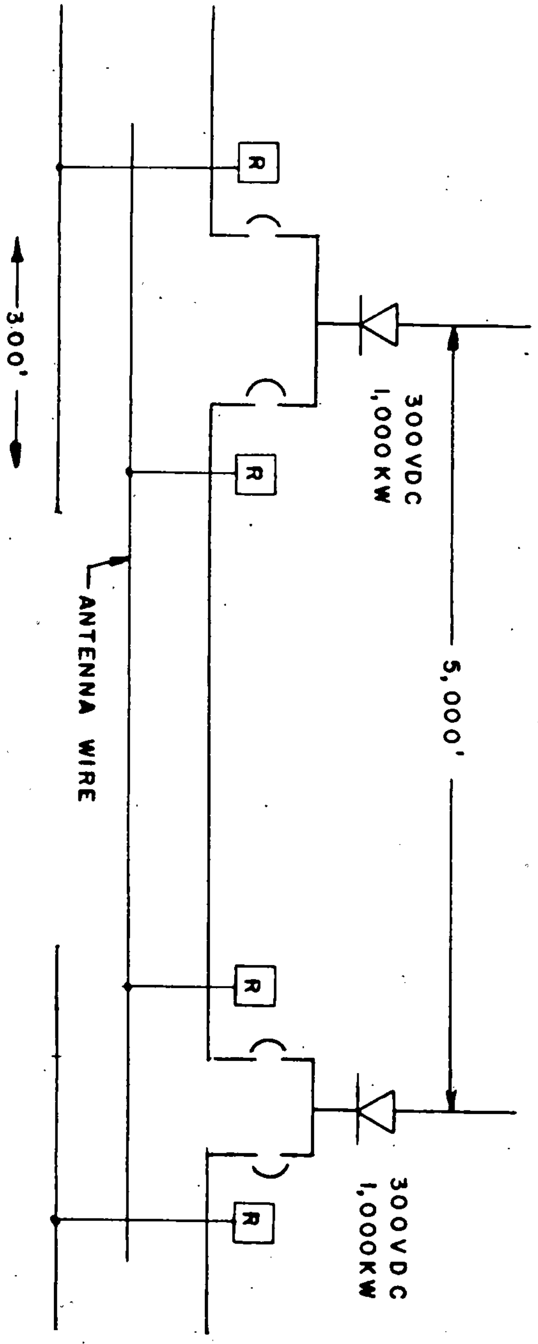

Figure 5

TROLLEY WIRE PROTECTION BY
SIMPLIFIED DISCRIMINATING CIRCUIT BREAKER

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ABSTRACT

A simplified discriminating circuit breaker concept, developed under Bureau of Mines Contract HO 122058, is discussed and the cost payback time of such a scheme is evaluated. An original discriminating breaker scheme to detect faults in excess of 15 amperes, was reported in 1975. However, by modifying this scheme to detect faults in excess of 150 amperes, considerable simplifications have resulted which make the system less costly and easier to maintain.

In operation, a high-frequency voltage is superimposed on the trolley wire, and ac current relays detect faults near substations. Faults remote from substations are detected by ac undervoltage relays. A pilot wire alongside the trolley wire carries signals to coordinate dc system breakers, and interrupt all sources feeding power to a fault. By making the pilot wire fail-safe, it provides a limited, but very simple means of trolley-wire protection independently of the fault detectors.

SUMMARY AND CONCLUSIONS

A typical coal mine dc trolley-wire system uses an overhead, 300-volt feeder cable and trolley wire, with ground return through the rails. Because the normal load currents flow through ground, it is difficult to detect unwanted or illegitimate loads, which also flow through ground. Illegitimate loads are capable of starting fires even though they may be much less than normal load currents, and means to detect them can save lives and money.

Working under program HO 122058, sponsored by the Bureau of Mines, a technique was developed in 1975 whereby arcing, and other types of fault, could be detected as illegitimate loads, because of the low impedance these faults present to ac current. To implement this technique, a 3-kHz voltage is impressed across the trolley wire, and faults are then detected by the flow of 3 kHz current. Many of the mine small dc loads,such as jeeps, have sufficiently high inductance to prevent significant-3 kHz current from flowing, but larger legitimate loads, such as locomotives, have to be equipped with filters to raise their impedance at 3 kHz. Applying these techniques, it was found possible to detect fault impedances of about 20 ohms or less, which corresponds to illegitimate loads of 15 amperes or more.(1,2,3) This method of fault detection was evaluated on a limited scale in two coal mines; it was very satisfactory in performance, and components of the system were tested below ground over a 4-year period. However, it was found difficult to maintain the filtering equipment needed on most of the mine vehicles. Although very satisfactory electrically, the equipments had to be mounted in exposed areas where they were subjected to severe mechanical stress.

Because of these difficulties, a simplified method was sought in which filters are only needed on the largest of vehicles, say greater than 25 tons. It was estimated that fault currents in excess of about 150 amperes could be detected by a similar method of injecting 3 kHz ac voltage on the trolley wire if additional ac undervoltage detectors were deployed. In this modified scheme, 3-kHz ac current detectors are used to detect illegitimate loads up to about 1200 feet from the substation. For more remote faults, the inductance of the trolley wire prevents adequate high frequency current from flowing; however, the same inductance causes substantial high-frequency voltage drop which is recognized by 3 kHz ac undervoltage detectors placed remote from the substation.

Work by Hall, et al, has indicated that the probability of sustained arcing faults on 300 volt trolley systems is much less likely for currents below about 200 amperes.(4) This is because the arc voltage for currents less than 200 amperes increases rapidly with decreasing current and the arc easily extinguishes itself.

The combination of current and voltage detectors in the new discriminating-circuit-breaker system permits illegitimate loads in excess of about 150 amperes to be detected without recourse to filters on any except the largest vehicles. The system is being installed for tests at Federal #1 mine of the Eastern Coal Company and is described in this paper.

COST/BENEFIT ANALYSIS

Over a 25-year period from 1952 to 1977, there were 127 coal mine fires involving the trolley system which were investigated by Federal Personnel.(4) Thirty-eight persons were killed and 25 people injured in these mishaps. At least 80 of these reportable fires were of a type which could have been prevented by the discriminating circuit breaker system. Single events include for example ten injured and 45 days lost production in 1954, three fatalities and many months lost production in 1971, nine deaths and mine closed for a long period in 1972, six months lost production in 1974 and a coal mine fire costing an estimated $14 million in lost tonnage in 1977. There is no way to account for the human tragedy in these statistics, neither is it possible to determine the number of fires that were not investigated, however, some simple calculations can be attempted to determine the economic value of a scheme for preventing fires caused by trolley wire illegitimate loads.

Considering only the reported lost time in the 80 applicable cases, a mine fire of this type costs, on the average, 13 days of lost production. At 500 tons a day and $35 per ton, this would amount to about $225,000. This compares to an initial cost of $30,000 to $60,000 for a discriminating circuit breaker system. Of course, there is only a small probability that any particular mine will experience a reportable haulageway fire, so that from this viewpoint, the expenditure for the system must be considered as a type of insurance.

If we consider only non-reportable fault conditions on the haulageway, we find that there is a probable continuous benefit to be obtained from the discriminating circuit breaker. Even though a fire is not started, equipment is often stressed and damaged by short circuits. Such damage can be expected to be much reduced due to quick response of the discriminating circuit breaker. Inquires within the industry indicate that such incidents may occur, on the average, about two to five times per year. When there is trouble on the haulageway, inby production comes to a halt (assuming no belt haulage). Average time to repair the damage is 4 hours. If we assume a 150 worker/shift mine with one-half the workers idled by the outage and equate one man-hour of labor to one ton of coal at $35 per ton, the annual worth of a trolley-wire protection scheme is estimated as:

Annual worth of trolley- = 2-5 (mishaps) x 4 (hours-to-repair)
wire protection x 75 (workers) x 35 ($/man-hour)
= $21,000-$52,500

Again, the initial cost of a discriminating circuit breaker system is estimated to be in the range of $30,000 to $60,000. Therefore, the pay-back time is of the order of two years. This would normally be considered an acceptable pay-back period and trolley-wire protection against unwanted loads appears to be justified on economic grounds alone.

POWER SYSTEM ARRANGEMENTS

A first requirement of any discriminating circuit breaker system is that having determined the existence of an illegitimate load, the appropriate substation dc breakers are caused to interrupt and remain open until the fault is removed. Each coal mine has its own special power system interconnections; however, two basic methods have been encountered. These are represented in Figure 1.

In Figure 1(a), a single breaker is used at each substation and the mine power system is broken into various sections by means of trolley gaps. A load in the section D_1-D_2, for example, would only receive power from substation S_2. To isolate a fault occurring anywhere in this section, only breaker B_2 needs to be opened. With this power distribution arrangement, it is dangerous to bridge a trolley gap if system protection is provided by dc breakers equipped only with simple overcurrent trip. If the trolley gaps are bridged and a fault occurs, only the breakers near the fault will receive enough current to trip.

At long distances from the fault, the total cable resistance may be too large to permit sufficient current to trip the remaining breakers. If a discriminating circuit breaker is used, the gaps could be bridged safely, however, a fault will then disable all substations capable of feeder power to the fault. If all trolley gaps are bridged, then a single fault would disable all power; clearly an undesirable feature and it is not recommended to bridge the trolley gaps.

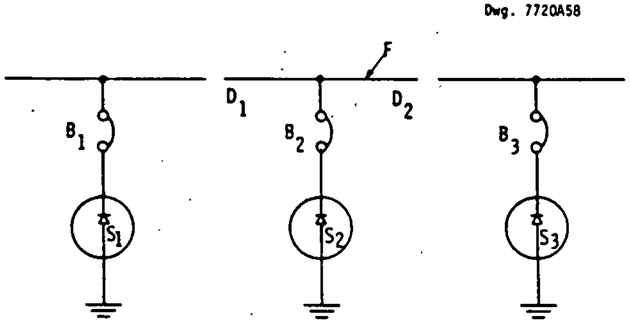

Fig. 1(a) Mine dc power system with single substation breaker

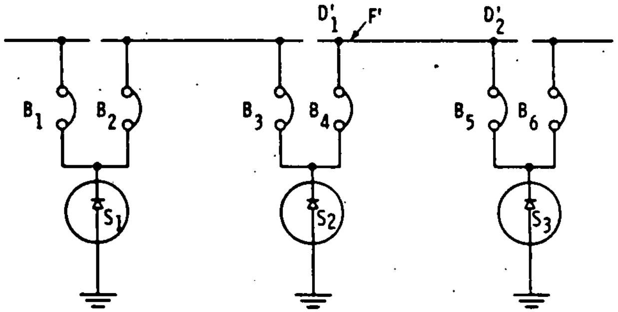

Fig. 1(b) Mine dc power system with double substation breakers

Fig. 1 Illustrating mine dc power system variation

The arrangement of Figure 1(b) uses two breakers to control power in each section, and loads receive power from all substations, however, this power is readily controlled. For example, a load in section D_1-D_2 can easily be isolated by opening breakers B_4 and B_5. In this case, power remains available to the rest of the mine system.

A further important feature of any discriminating-circuit-breaker system is the ability to locate a fault when the breakers have opened. The system described in this paper provides this feature.

DISCRIMINATING CIRCUIT BREAKER CONCEPT

The basic discriminating circuit breaker system is shown in Figure 2. Referring to this figure, oscillators at each substation superimpose 10 volts at 3 kHz on the trolley wire and appropriate current and voltage detectors are included.

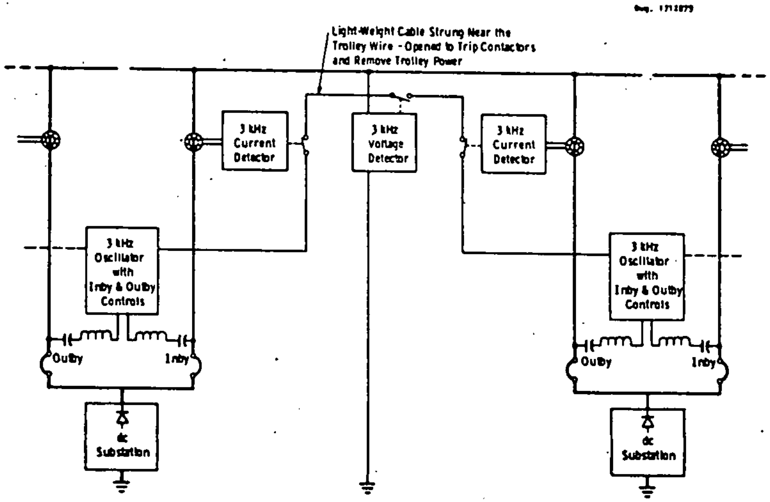

Fig. 2. Simplified discriminating circuit breaker system.

A light-weight cable comprising three twisted pairs of insulated 20 gauge wire is strung alongside the trolley wire to carry signals for the system. For the substation dc breaker to be able to close, the discriminating circuit must receive proper data through the signaling cable. Thus, if the signal cable is broken by a roof fall, signals are not transmitted and the dc power cannot be energized. Also, if the detector units indicate a faulty condition, both inby and outby breakers are prevented from closing. The final output of the discriminating-breaker system is a normally-open contact which is connected in series with the dc breaker conventional overcurrent trip. Everything must be functioning for this contact to close; however, for test purposes, it is easily bypassed by a simple knife switch.

In a typical coal mine, the substations are about one mile apart and 3-kHz current detectors, shown in Figure 2, satisfactorily detect faults up to about 1200 feet from the substation. The current detectors incorporate an air-cored current transformer tuned to 3 kHz and having a bandwidth of about 200 Hz. With this selectivity, the effects of ripple voltages on the power system are minimized. The output of the current transformer is rectified and directly operates a sensitive relay. Typically, the relay is operated for 3-kHz currents in excess of about 1.5 amperes; however, adjustment is provided and a time delay of 0.2 seconds is included to prevent spurious tripping due to momentary overloads, such as caused by electric switches.

Illegitimate loads remote from the substation are detected by loss of 3 kHz voltage on the trolley wire, and the voltage detector is a self-activated device which is able to energize a sensitive relay for 3 kHz voltages as low as 2.0 volts. Typically, the undervoltage trip is set at about 3.5 volts and a time delay of about 0.3 seconds is used to prevent spurious tripping. For long distances, more than one undervoltage detector is necessary to achieve the required sensitivity to illegitimate loads. For example, three undervoltage detectors would be used for a 6000 foot distance between substations.

The overcurrent and undervoltage detector units incorporate contacts in series with the signal wire such that if continuity is lost, both inby and outby circuit breakers are opened. Schematics of the current and voltage detectors are shown in Figures 3 and 4.

It should be noted that the 3-kHz ac signal is superimposed on the dc distribution system even though the dc breakers are open. By this means, the discriminating circuit breaker is prevented from closing into a fault condition. Also, the location of a fault can be determined by using a hand held 3-kHz voltmeter and walking along the haulageway, and noting where the voltage is minimum. Ultimately, it is expected that by interpreting data from the current and voltage detectors, automatic indication of the fault location can be predicted,

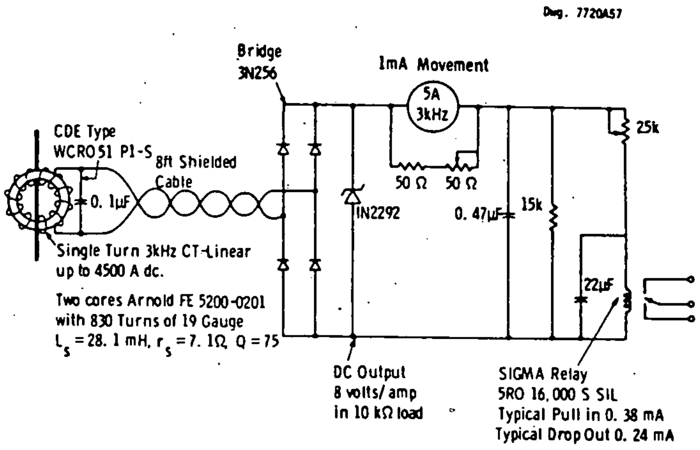

Fig. 3 3 kHz current detector

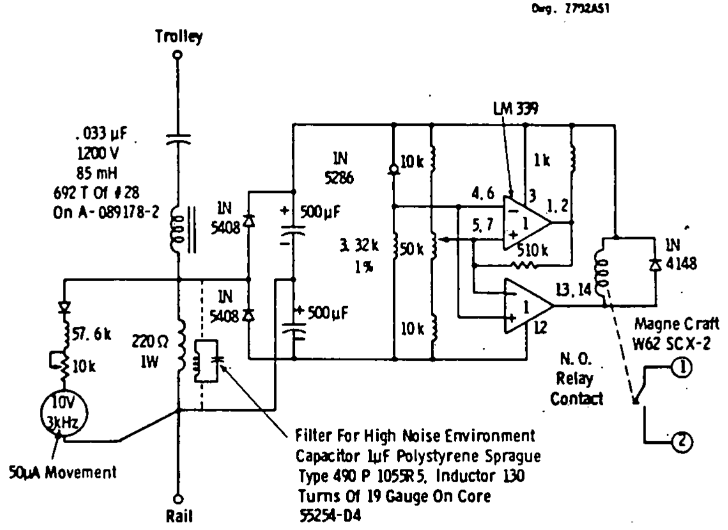

Fig. 4 3 kHz voltage detector

and some type of digital instrument at the substation will indicate how far away the fault is located.

The discriminating system can be applied equally well to the two types of mine power system arrangement shown in Figure 1. A summary of features addressed in the design are highlighted as follows:

- Illegitimate loads in excess of 150 amperes are detected.
- Filters are only needed on vehicles greater than 25 tons.
- System operates with one or more power substations out of service.
- Breaks in the signal cable shut down power to that section. Power can be controlled manually by incorporating switches anywhere along this cable.
- Junctions where three or more substations feed power can be protected.
- Equipment uses low-power, solid-state electronic equipment which has given typically 3-year trouble-free performance below ground without maintenance.
- Rail systems that have poor grounding give high impedance and are detected.

SYSTEM DESIGN

A basic system design must take into account the impedance of the rail system and impedance of the legitimate loads. Typically a well bonded and grounded rail system will have a 3-kHz impedance of about 6.5 Ω/1000 feet; however, this can be as high as 20 Ω/1000 feet if the grounding is poor.

The 3-kHz impedance of some typical loads is shown in Table 1.

Table 1

LOCOMOTIVE IMPEDANCE PARAMETERS AT 3 kHz

Locomotive Rating Tons	Nominal Motor Rating Horsepower	Parallel Inductance Impedance Ω	Parallel Resistance (Including Lights) Ω	Effective Series Impedance Ω	Angle
2 x 13	400	9.6	22	8.8	66.4°
25	320	12.0	22	10.5	61.0°
20	260	15.0	22	12.3	56.0°
15	200	20.0	22	14.7	48.0°
10	130	30.0	22	17.7	36.0°

Armed with the basic cable and equipment information, the overall design becomes an ac circuit analysis problem to ensure that faults of 2 ohms or less activate one or more of the 3-kHz detectors, and that legitimate loads do not. We have found that a computer simulation is desirable to accommodate the complexity of these calculations, which include the effects of distributed loads, such as pumps and lights. Typically the arrangement is simulated by a circuit with lumped parameters representing every 500 feet of trolley wire, and incorporating about 14 nodes for calculating purposes.

LABORATORY SIMULATION

A complete laboratory simulation of a design prepared for the No. 22 coal mine of the Bethlehem Mines Corporation is shown schematically in Figure 5 and by photograph in Figure 6. This laboratory simulation was used to verify the overall system performance under various simulated fault and operating conditions, including equipment failures. Performance was as hoped for and it is noted that the 3-kHz detectors are set to operate with a 50% safety margin. For example, if the known legitimate load draws a maximum 3 kHz current of 1.0 amperes, then the 3-kHz overcurrent trip would be set at a minimum of 1.5 amperes.

CONCLUSIONS

The simplified discriminating circuit breaker system described, provides three important features, namely

1) Protects against illegitimate trolley wire loads in excess of 150 amperes.

2) Provides a simple means for manual trip at any point in the coal mine.

3) Has a pay-back period of about two years.

The basic components of the system, such as oscillator, power supplies and detector have been satisfactorily tested in operating coal mine environments, and a completely operational system with control over the dc circuit breaker is currently being installed for evaluation.

Detailed design information for the various equipments needed to implement a discriminating circuit breaker system are available from either of the authors.

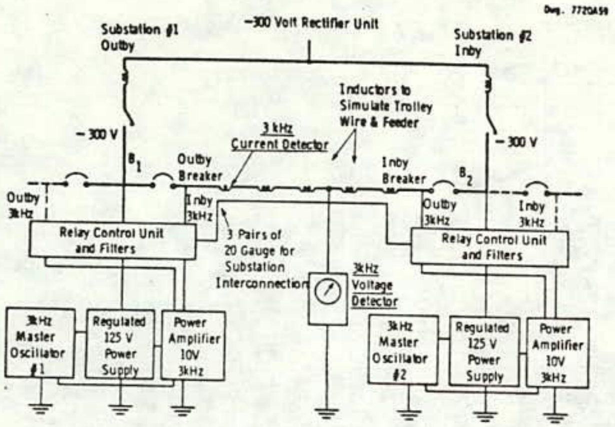

Fig. 5 Schematic arrangement of simplified discriminating circuit breaker applied to No. 22 coal mine

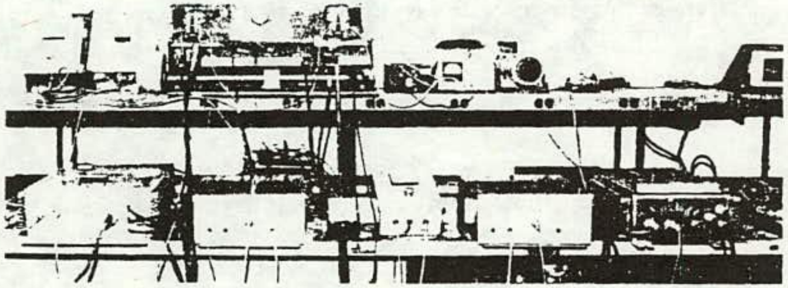

Fig. 6 Laboratory simulation of simplified discriminating circuit breaker for No. 22 coal mine

Note: Simulation includes two master oscillators, two power oscillators, two ITE relay control units, one current detector, one voltage detector, one portable voltage detector to locate fault, two power supplies, two simulated ITE breakers, 6000 ft. of trolley system, one 25 ton locomotive, and one 200 to 350 volt dc substation.

ACKNOWLEDGEMENTS

The authors are indebted to the U.S. Bureau of Mines and the Westinghouse Electric Corporation for permission to publish this paper. The work was performed under Contract HO 122058. A number of coal companies and many of their personnel have contributed to this project, and a partial listing is given below:

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Eastern Coal Co. - Mr. J. Tysdale, Mr. R. Garrett and Mr. J. Davies

Finally, the encouragement provided by Mr. J. Murphy of the U.S. Bureau of Mines and Mr. R. P. Putkovich of the Westinghouse R&D Center, is gratefully acknowledged.

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1,2 U.S.B.M. Phase 1 and Phase 11 Contract Reports on Project HO 122058.

3 D. A. Paice and A. B. Shimp, Discriminating Protection for Trolley Wires, IEEE Industry Application Society Annual Meeting, Atlanta, Sept., 1975.

4 P. M. Hall, K. Myers and W. S. Vilcheck, "Arcing Faults on Direct Current Trolley Systems", Proceedings of the Fourth WVU Conference on Coal Mine Electrotechnology, August, 1978.

DEMONSTRATION OF THE DISCRIMINATING CIRCUIT BREAKER (DISCB)

By Michael R. Yenchek[1]

ABSTRACT

The evolution of the DISCB concept and theory of operation are described briefly. Laboratory test results with a simulated mine haulageway are included and illustrate detector operation, and the effects of rectifier ripple, arcing, and deteriorating track bonding. Future Federal Bureau of Mines laboratory and fieldwork plans are outlined in conclusion along with an appendix containing important points for consideration during in-mine installation.

INTRODUCTION

Track haulage systems in United States underground coal mines operate at 300 to 600 V dc, one side of which returns to the source through grounded rails. Electrical faults on these systems are a major cause of mine fires, and once having caused a fire, can also block egress from the mine and contaminate the fresh air supply.

From 1952 to 1977, Federal personnel investigated 127 such fires. At least 80 would have been prevented if suitable electrical protection had been available.

The simple overcurrent sensing devices commonly used in haulage systems date back to the 1920's despite advances in electrical and electronic technology. What is needed is a protection scheme that permits the flow of thousands of amperes of normal motor currents, but responds rapidly to the low-level ground fault currents associated with incendiary arcing.

THE DISCB CONCEPT

In the early 1960's, French researchers (8)[2] successfully developed a scheme for accomplishing the required discrimination by impressing an audio frequency tone on the trolley line at each rectifier station and monitoring its magnitude. The need for modification of the system, to accommodate the heavier rolling stock prevalant in U. S. mines, led to Bureau of Mines research contract H0122058 with Westinghouse Electric Corp. in 1972.

Through the DISCB concept, arcing and other types of faults are detected as illegitimate loads because of the low impedance they present to 3-kHz-ac current. This frequency was chosen because it gives good signal transmission on underground trolley wires, yet is high enough to permit a clean separation of the signal from normal system noise.

Many small mobile loads such as jeeps have sufficient motor inductance to prevent significant 3-kHz current from flowing, however, larger haulage locomotives must be equipped with filters to raise their impedance at 3 kHz as shown in figure 1. Applying this technique, Westinghouse (13) found it possible to detect illegitimate impedances of 20 Ω or less, corresponding to fault currents of 15 A or more on a 300-V system. However, during underground tests the filtering devices needed on most mine vehicles presented a problem. This equipment had to be mounted in exposed areas and was subjected to severe mechanical stress. Because of this a simplified method was sought that significantly reduced the number of filters needed.

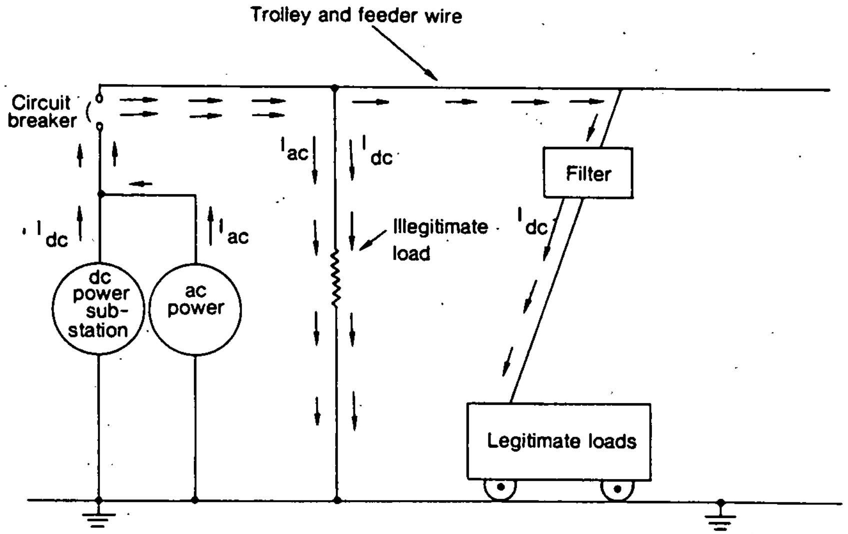

FIGURE 1. - DISCB current flow.

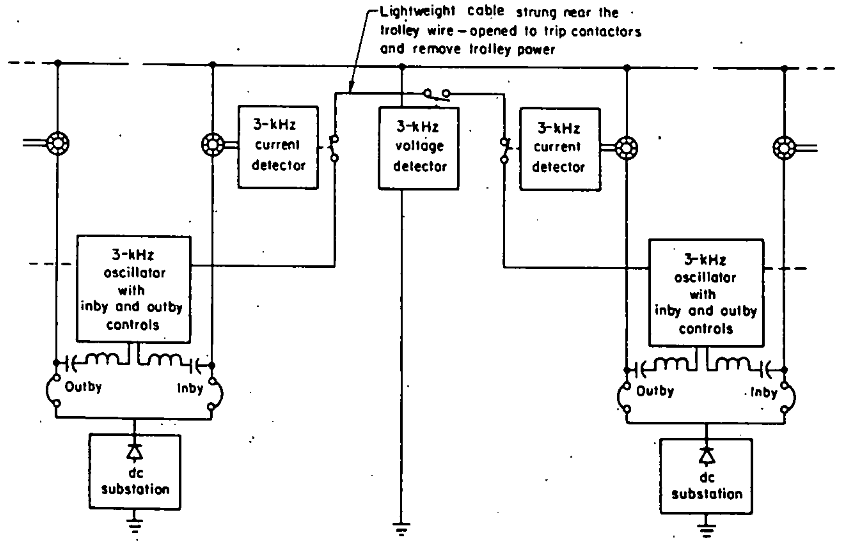

FIGURE 2. - Simplified DISCB system.

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[1] Electrical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

[2] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

Work by Mine Safety and Health Administration (MSHA) personnel (4) indicated that arcing faults on 300-V trolley systems are much less likely to be sustained at current levels smaller than 200 A. Below this limit arc voltage increases rapidly and the arc easily extinguishes itself. Thus a discriminating circuit breaker system capable of detecting any faults in excess of 150 A will provide substantial protection.

In the final modified design, 3-kHz-ac current detectors are used to detect illegitimate loads up to 1,200 ft from the substation. For more remote faults the inductance of the trolley wire prevents adequate high frequency current from flowing; however, the same inductance causes a substantial high frequency voltage drop which can be recognized by a 3-kHz-ac undervoltage detector remote from the substation (see fig. 2). This combination of voltage and current detectors provides detection of any illegitimate load in excess of 150 A, without recourse to filters on other than the largest vehicles.

In operation a lightweight pilot wire alongside the trolley wire carries signals to coordinate the operation of dc breakers at the various sources to interrupt all lines feeding the fault. This wire also provides additional protection, in that if the cable is broken by a roof fall, the dc power is interrupted and cannot be energized until repairs have been made.

System Benefits

If those fault conditions on coal mine track haulageways which are usually not reported are considered, it is found that there is a probable continuous benefit to be derived from discriminating circuit breakers. Not all short circuits start fires but they often stress and damage equipment. This damage can be significantly reduced with the quick response of the discriminating circuit breakers. Inquiries within the industry indicate that such incidents may occur about two to five times a year. Inby production stops for an average of 4 hours while repairs are made. If a 150-worker-per shift mine with one-third the workers idled by the outage is assumed, and equating 1 man-hour of labor to 1 ton of coal at \$40 per ton, the annual worth of a trolley wire protection scheme is estimated as 2 to 5 (mishaps) × 4 (hours to repairs) × 50 (workers) × 40 (\$ man-hour) = \$16,000 to \$40,000.

If the initial cost of a discriminating circuit breaker system is estimated to be in the range of \$35,000 to \$70,000, the payback time is of the order of 2 years, an acceptable period. Thus trolley wire protection appears justified on economic grounds alone (11, p. 12).

Of all the protection schemes proposed to date, the DISCB offers the best hope of functioning well, given proper installation. It does not depend on uncontrolled characteristics such as rectifier ripple, transient waveforms, or dI/dt level sensing for its basic operation. Also, the DISCB can be employed on any existing haulageway with minimal modifications to the haulage equipment. Finally, it utilizes low-power solid-state electronics (fig. 3) that can give virtually maintenance-free performance for many years.

After the development of the discriminating circuit breaker, a system was installed underground and exposed to typical haulage conditions including electrical power system fluctuations for over 5 years (see fig. 4). It performed satisfactorily but operated event counters in lieu of tripping circuit breakers. What remains to be demonstrated is that the system, in the long term, will work reliably and safely when actually protecting a mine haulageway. The appendix to this paper provides recommendations for field installation.

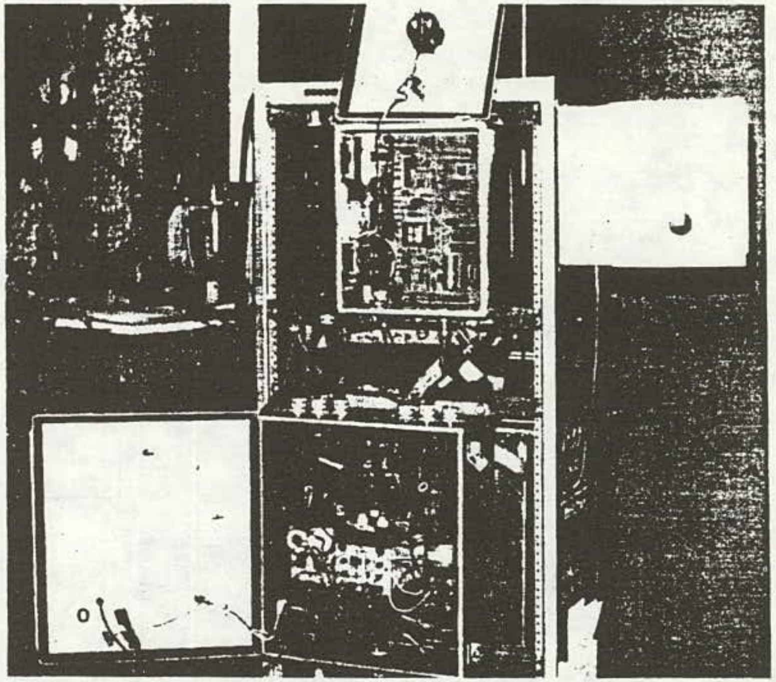

FIGURE 3. - DISCB internal components.

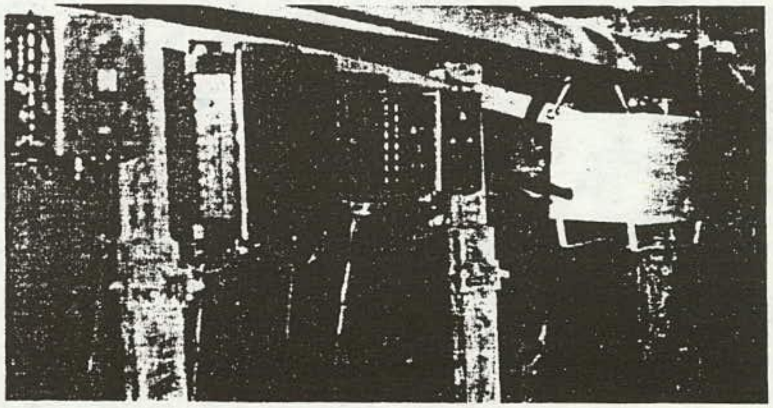

FIGURE 4. - DISCB control installed underground.

HAULAGEWAY MODEL

Background

The management of Federal No. 1 Mine of Eastern Associated Coal Co., Grant Town, W. Va., expressed an interest in utilizing the system to protect a 1-mile section in the oldest but still actively used area of the mine. Prior to commitment they requested a laboratory demonstration of the DISCB basic functions using prototype hardware and a simulation of the particular haulage section. The Bureau of Mines, therefore, has recently constructed and successsfully operated a lumped parameter simulation of the rail section, protected by the actual DISCB equipment.

Federal Haulageway

The Federal No. 1 Mine was visited to gather data on a portion of the rail haulage fed from a single 300-V source shown in figure 5. Two parallel track entries, one for loads and the other for empties, connect the rotary dump area with the active sections of the mine. At the No. 1 substation a 500-kW mercury arc hewittic rectifier was tied into the system through a circuit breaker having an overcurrent setting of 2,500 A. It has since been replaced with a solid-state unit.

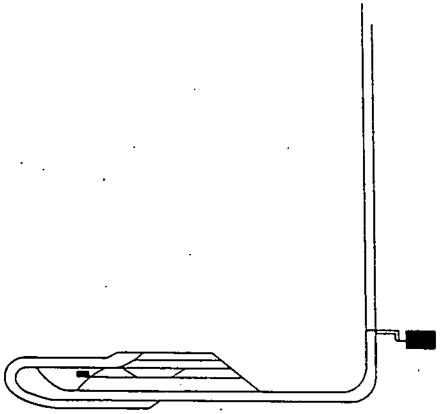

FIGURE 5. - Portion of Federal No. 1 haulage used for model.

The positive No. 9 section copper trolley is paralleled part of the way by a 1,590 kcmil aluminum feeder cable, tied to the trolley at 200-ft intervals. The track conductors consist of 85-lb double-bonded rails. The distance between trolley and feeder is 12 in; between trolley and rail it averages 72 in.

The available locomotive loads are: Two 50-ton locomotives with four 160-hp motors, six 37-ton locomotives with four 120-hp motors, and two 15-ton locomotives with two 150-hp motors. Numerous utility vehicles of 150 hp and less are also used.

Theoretical Analysis

The rectifier can be represented by the equivalent circuit shown in figure 6.

Mine rectifiers generally are found in one of two configurations: The three-phase bridge and the six-phase double wye (12). It can be shown that the operation of both of these circuits is equivalent (14). The steady-state regulation curve of either circuit is shown in figure 7.

The effective source resistance, V/I, is not constant but is lower in the overload range than for the short circuit. The source resistance, R_S, may be calculated given the per-unit reactance and resistance of the transformer rectifier. For a 500-kW unit, typically percent R equals 1.1, percent X equals 7.5, and percent Z equals 7.6.

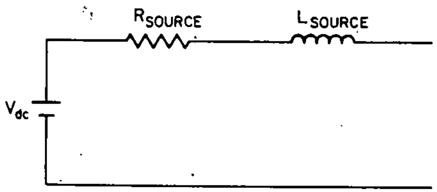

FIGURE 6. - Direct current mine power supply.

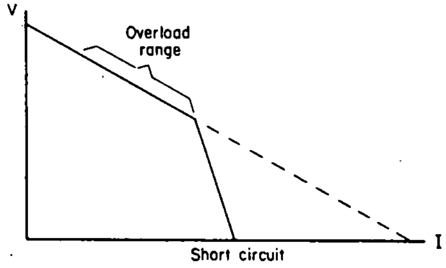

FIGURE 7. - Rectifier voltage regulation.

Assuming an infinitely stiff source feeding a 500-kW three-phase bridge rectifier, the ac impedance can be calculated as (3, pp. 12-17)

$$V_{LINE-NEUTRAL} = \frac{V_{DC}}{1.35\sqrt{3}} = \frac{300}{1.35\sqrt{3}} = 128 \text{ V},$$

$$I_{LINE} = 0.816\ I_{DC} = 0.816\ (1,666) = 1,360 \text{ A},$$

and

$$Z_{BASE} = 128/1,360 = 0.094\ \Omega.$$

Therefore,

$$R_{AC} = (0.11)(0.094\ \Omega) = 1.03\ \text{m}\Omega,$$

$$Z_{AC} = (0.076)(0.094\ \Omega) = 7.14\ \text{m}\Omega,$$

$$X_{AC} = (0.075)(0.094\ \Omega) = 7.05\ \text{m}\Omega,$$

and

$$L_{AC} = X/377 = \frac{7.05\ (10^{-3})}{377} = 18.7\ \mu\text{H}.$$

For the overload range the equivalent dc circuit impedance is (14)

$$R_{SOURCE} = 6\ fL_{AC} + 2\ R_{AC} = (360)(18.7)10^{-6} + 2(1.03)(10^{-3})$$

$$= 8.79\ \text{m}\Omega.$$

For the short-circuit case

$$R_{SOURCE} = \sqrt{3}\ Z_{AC} = \sqrt{3}\ (7.14)(10^{-3})$$

$$= 12.37\ \text{m}\Omega$$

The equivalent source inductance is essentially constant and equal to (14)

$$L_{SOURCE} = 1.65\ L_{AC} = 1.65(18.7)10^{-6} = 31\ \mu\text{H}.$$

Since the DISCB detects relatively low levels of fault current, the equivalent source resistance for the overload range was chosen for the model.

The theoretical dc resistance at 20° C for 400 kcmil, figure 9 hard-drawn copper trolley wire is (1) 0.02687 Ω/1,000 ft. For the 1,590 kcmil aluminum feeder it is (10) 0.01091 Ω/1,000 ft, or roughly equivalent to 1,000 kcmil copper. So the paralleled trolley and feeder resistance is 0.00755 Ω/1,000 ft

The resistance of two 85-lb rails cross-bonded at 200-ft intervals and having 33 bonded joints per rail per 1,000 ft is (6) 0.0064 Ω/1,000 ft.

Actual measurements (9) of unbonded joints indicate that their resistance averages 50 times that of a well-bonded joint. Resistances of unbonded 85-lb rail joints have been measured (2) to be 0.025 Ω. In simulating poor bonding for a pair of 85-lb rail it is assumed that 70 pct of the joints are unbonded. Thus the dc resistance becomes 0.335 Ω/1,000 ft.

Because the DISCB imposes a 3-kHz signal directly onto the haulage system conductors, the importance of skin effect was considered. Let R' be the effective ac resistance for a linear cylinderical conductor and R the dc resistance; then

$$R' = kR,$$

where k can be determined from standard references (3, p. 4-29) in terms of

$$x = 0.0636 \sqrt{\frac{f\mu}{R}}$$

where f = frequency in hertz,

μ = magnetic primability of the conductor (assumed constant),

and R = dc resistance at 20° C.

For the 9-section copper trolley at 3,000 Hz,

$$x = 0.0636 \sqrt{\frac{3(10^3)(1)}{0.142}} = 9.25,\ K = 3.60,$$

so the resistance of the trolley to a 3-kHz voltage is 0.09734 Ω/1,000 ft. For the aluminum feeder x = 14.92, k = 5.53, so ac resistance is 0.0637 Ω/1,000 ft and, for trolley and feeder is parallel, R'_{3kHz} = 0.0373 Ω/1,000.

For steel rails the value of μ, and thus R', will vary and should be determined by test. Measured (16) values of ac resistance versus current indicate that between 500 and 800 A, R' is almost constant and a maximum. As this range is of interest for the DISCB, an approximate extrapolation of the curves yielded

$$R'_{3kHz} = 0.3273\ \Omega/1,000\ \text{ft}$$

for 85-lb double-bonded track.

The inductance of any trolley system configuration may be calculated theoretically by several methods (2, 7) with the following assumptions:

1. All conductors are nonmagnetic.
2. All conductors are cylindrical.
3. Constant spacing exists between conductors.
4. Rail self-inductance is negligible.
5. The cross-sectional area of feeder is added to trolley and/or rails.

Accurate field measurements of system inductance yields results in substantial agreement with the theoretical values. Therefore, it was not considered necessary to choose inductance values for the haulage model based upon rigorous theoretical calculations; instead, they are reasonable estimates from field surveys (5, pp. 9-1, 9-13) of systems similar to Federal No. 1. Thus

$$L_{9S\&85\#} = 0.5\ \text{mH}/1,000\ \text{ft},\ X_L$$

$$= 9.3\ \Omega/1,000\ \text{ft at 3 kHz}$$

and

$$L_{9S||Al\&85\#} = 0.3\ \text{mH}/1,000\ \text{ft},\ X_L$$

$$= 5.7\ \Omega/1,000\ \text{ft at 3 kHz}.$$

In general, the use of parallel feeder conductors decreases inductance while greater conductor separation increases it.

The shunt capacitance between the system conductors can be determined by individually calculating capacitance to neutral points and combining the resultant values in series and parallel as necessary. The equation that is used is (15, pp. 77-83)

$$C_N = \frac{0.0388}{\log (D_I/R_I)}\ \mu\text{f/mile},$$

where C_N = the capacitance of a conductor to a neutral point,

R_I = the radius or equivalent radius of the conductor,

and D_I = the distance to the neutral point between conductors.

The values arrived at by these calculations are, for the trolley and or feeder and track, C_N equals 0.016 μF/1,000 ft; and for the trolley and track, C_N equals 0.005 μF/1,000 ft. The respective shunt capacitive reactances at 3 kHz are X_c equals 3.3 kΩ/1,000 ft and X_c equals 10.6 kΩ/1,000 ft. For modeling purposes the shunt capacitance was neglected.

Large mobile haulage loads on dc mine systems utilize series field dc motors. Empirical relationships for 300-V-dc motors show that the effective inductance can be approximated by (12, pp. 4-18)

$$La = 190/\text{hp rating (mH)}.$$

The circuit simulation is shown in figure 8. The starting resistance, R_s, can be varied to produce up to triple full load current. Stationary loads (11, p. 16) such as pumps and lights distributed along the haulage were simulated using 9C Ω per 500 ft.

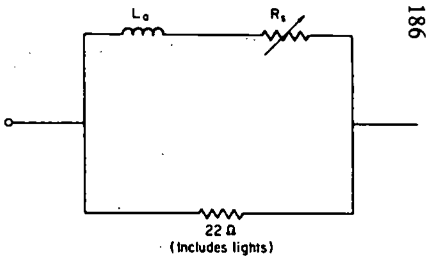

FIGURE 8. - Electrical model of mine haulage locomotive.

Construction of the Model

The actual haulage system routing was rearranged, as shown in figure 9, to fit on a 4- by 8-ft plywood board. It was subdivided into sections and simulated as shown in figure 10 where L is the system inductance per section length. The parallel combination of R_{AC} and R_{DC} in series with R simulates dc resistance, and R_{AC} + R, the ac resistance; L_{SK} is sufficiently large to approximate skin effect at 3 kHz. R_s represents distributed stationary loading and R_B, the high resistance of poor bonding (normally jumpered).

Owing to power source limitations in the lab, loading and fault simulations did not exceed 100 A dc. Number 8 square copper magnet wire was wound on the lathe to form inductors. Appropriate resistance values were obtained with nickel-chromium wire noninductively wound.

The demonstration board is shown in figure 11.

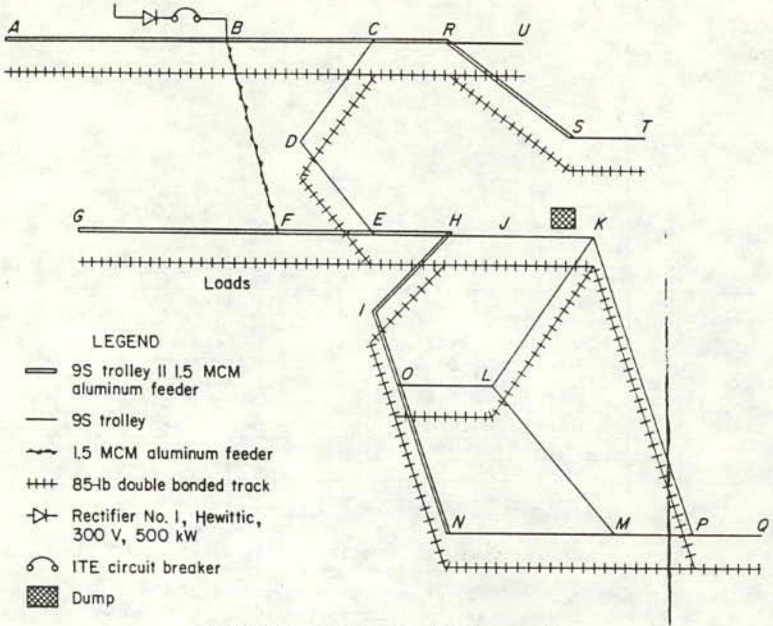

FIGURE 9. - Federal No. 1 haulage model.

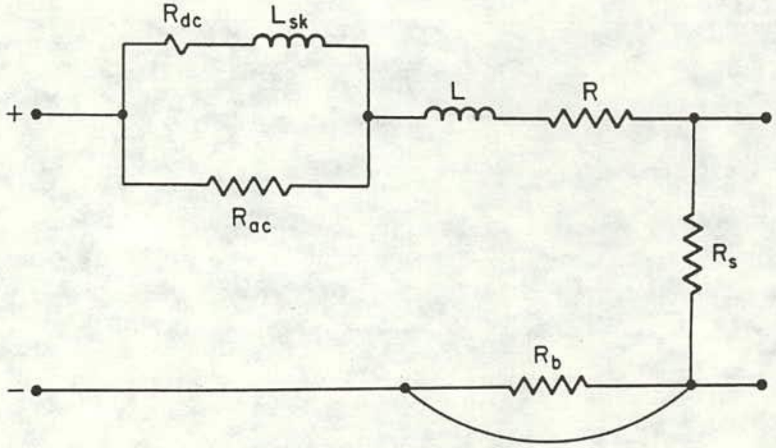

FIGURE 10. - Lumped haulage simulation.

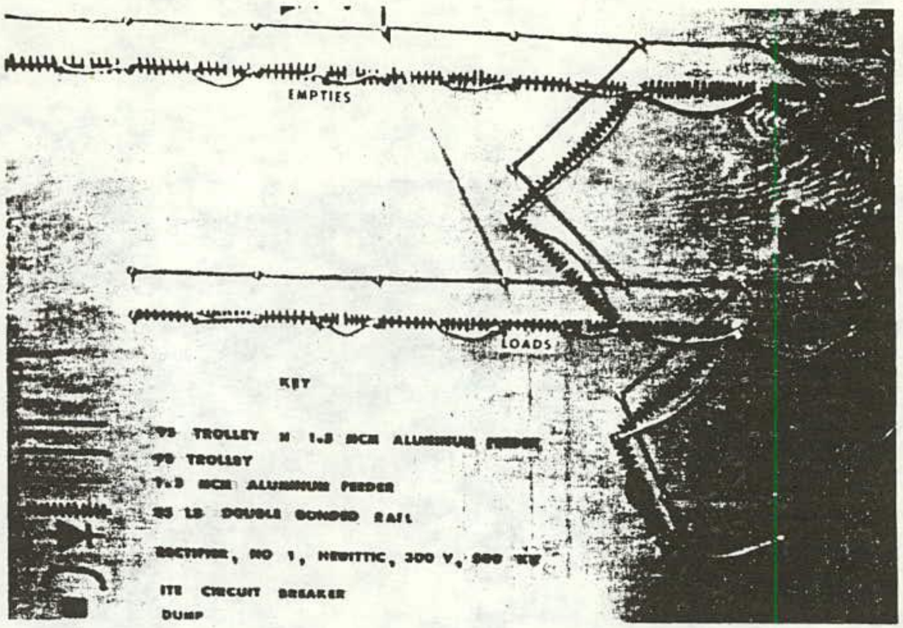

FIGURE 11. - Haulageway model.

LAB DEMONSTRATION

Current and Voltage Detection

Upon completion of the model the discriminating circuit breaker controls were connected to impress the 3-kHz signal on the system at the rectifier location as shown in figures 12 and 13. The 3-kHz current flow with no external mobile load or faults connected was 1.17 A as measured by the current detector. Referring to figure 9, with a 1.5-Ω resistive fault at point B, the rectifier, the 3-kHz current increases to 4.42 A; the current detector relay is activated and the circuit breaker trips. A simulated 15-ton locomotive placed at B drew 2.30 A at 3 kHz and did not trip the breaker.

Applying the fault at point A, 3,450 ft from the source, the total high frequency current increases slightly over the no-load value, to 1.24 A. This point is past the protective range of the current detector where audio current magnitude remains relatively unchanged for resistive faults remote from the substation.

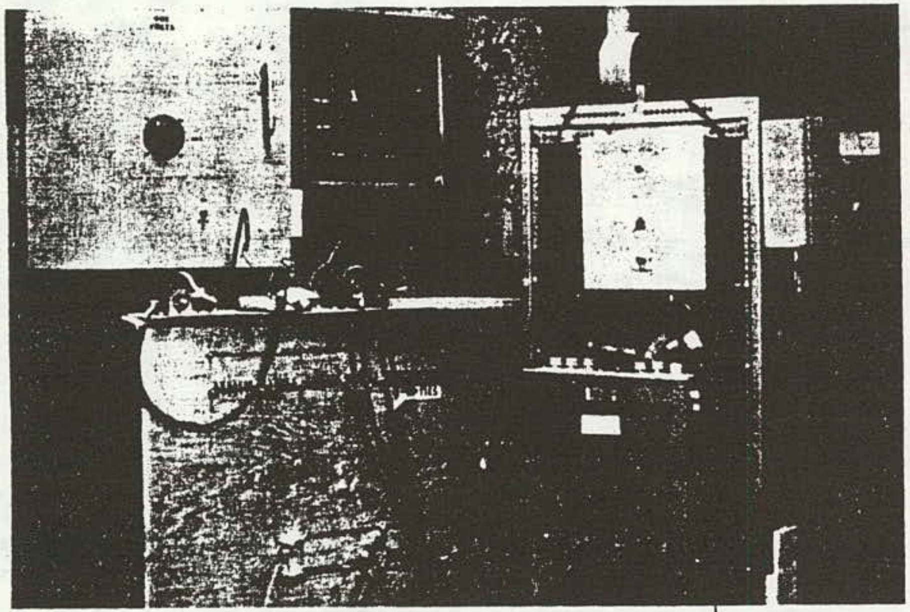

FIGURE 12. - Laboratory setup.

It is here that the DISCB voltage detector is needed and a simple example will illustrate this. Referring to table 1 the high frequency voltage was monitored (fig. 14) at six locations under normal, abnormal, and no-load conditions. Location B is at the substation while A, G, U, T, and Q are remote from it.

TABLE 1. - 3 kHz voltage variations

Load condition	Location					
	B	A	G	U	T	Q
No-load..................	8.0	6.7	6.3	6.8	6.9	7.1
1.5-Ω fault at B..........	6.1	5.0	4.8	5.2	5.3	5.4
15-ton locomotive at B....	7.1	5.9	5.7	6.0	6.1	6.3
1.5-Ω fault at A..........	7.8	.2	6.1	6.6	6.7	6.9
15-ton locomotive at A....	7.9	1.4	6.1	6.7	6.8	7.0
1.5-Ω fault at G..........	7.9	6.6	.1	6.7	6.8	7.0
15-ton locomotive at G....	7.9	6.6	1.3	6.7	6.8	7.0

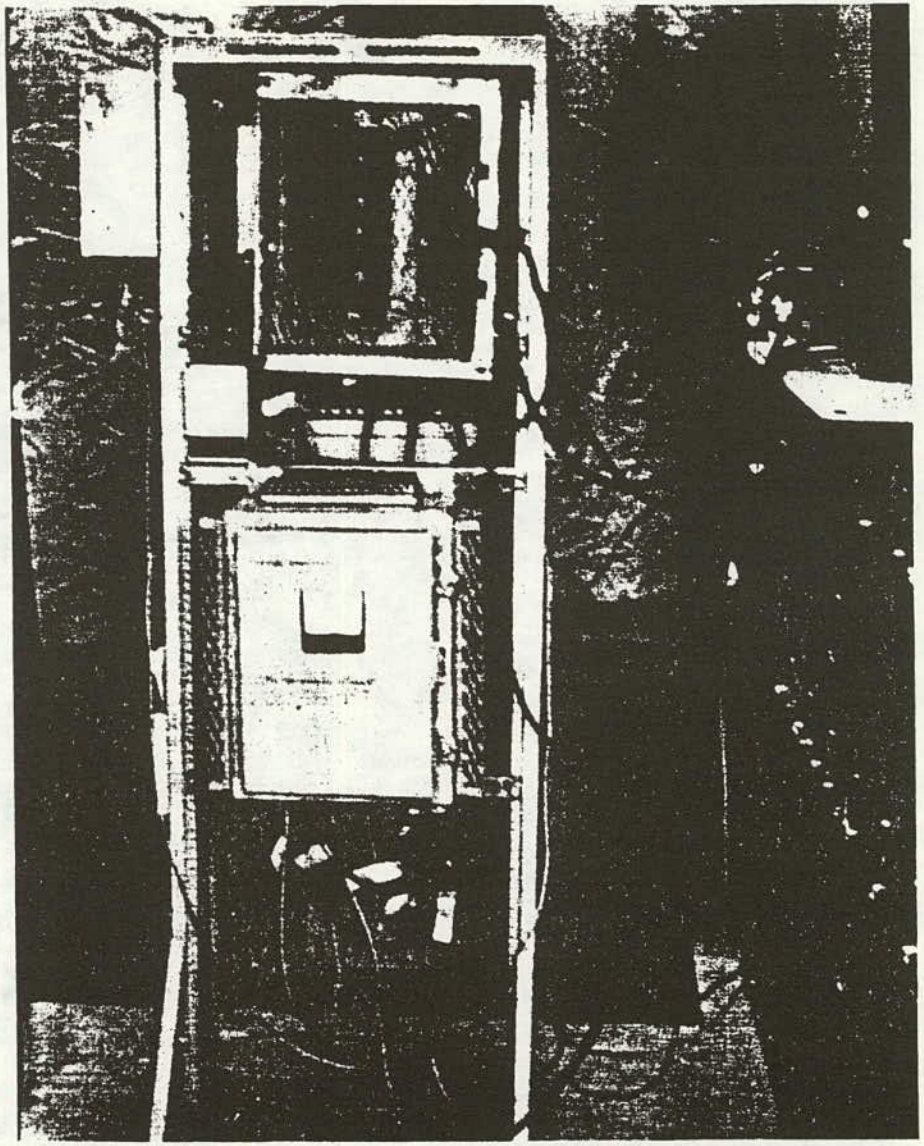

FIGURE 13. - DISCB controls at substation.

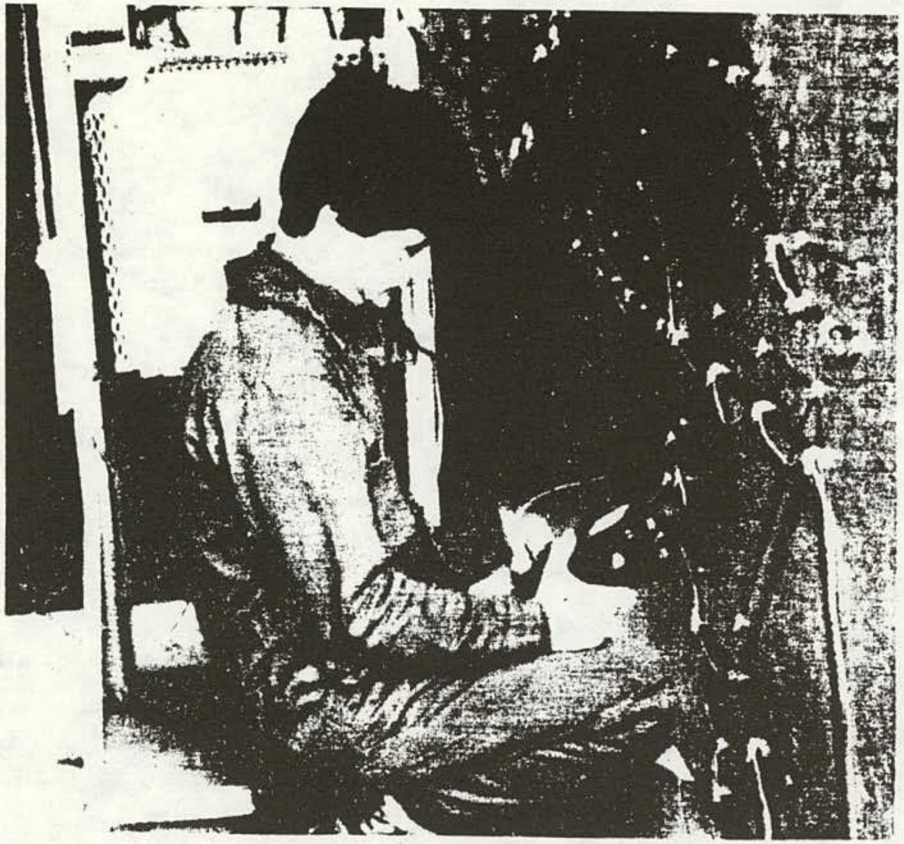

FIGURE 14. - Voltage measurements on model.

No-load is defined as that time when only distributed stationary loads such as pumps and lights are connected on the system. The high frequency voltage is a maximum at the rectifier and drops by 22 pct at the remotest point. With a fault near the rectifier the 3-kHz voltage throughout the system decreases 24 pct from the no-load value. The voltages at B for a fault or a locomotive differ by 15 pct. Since this margin between legitimate and illegitimate loads is insufficient for discrimination a voltage detector located near the source serves no purpose.

Away from the substation, high current loads and faults substantially alter the 3-kHz voltage distribution. With the fault at A the signal voltage there drops to 3 pct of the no-load value. It also drops substantially with a legitimate locomotive load there. However, now there is an 86-pct difference in the two voltages, large enough to adjust the setting of the voltage detector to protect against resistive faults. It is of interest to note that the voltage magnitude remains relatively unchanged at locations remote from the fault and the rectifier.

DISCB worst-case performance is illustrated in figure 15 with a voltage detector located 2,875 ft away from the rectifier at A. Through judicious placement of the voltage detectors it is possible to protect the entire system.

Active Impedance Multiplier

As described in the first section, the 3-kHz impedance of vehicles rated 25 tons and larger must be raised sufficiently to prevent nuisance tripping. This is accomplished by mounting an active impedance multiplier (fig. 16) on board large mobile loads. Laboratory testing of the multiplier with a simulated 37-ton locomotive yielded satisfactory results.

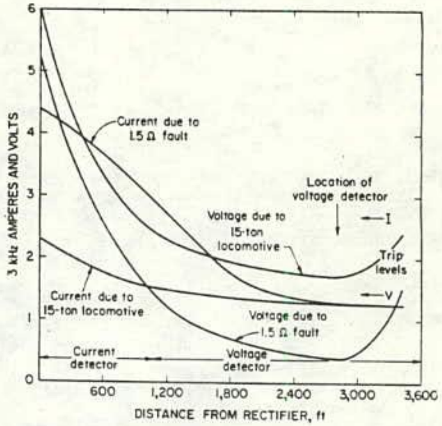

FIGURE 15. - DISCB protection.

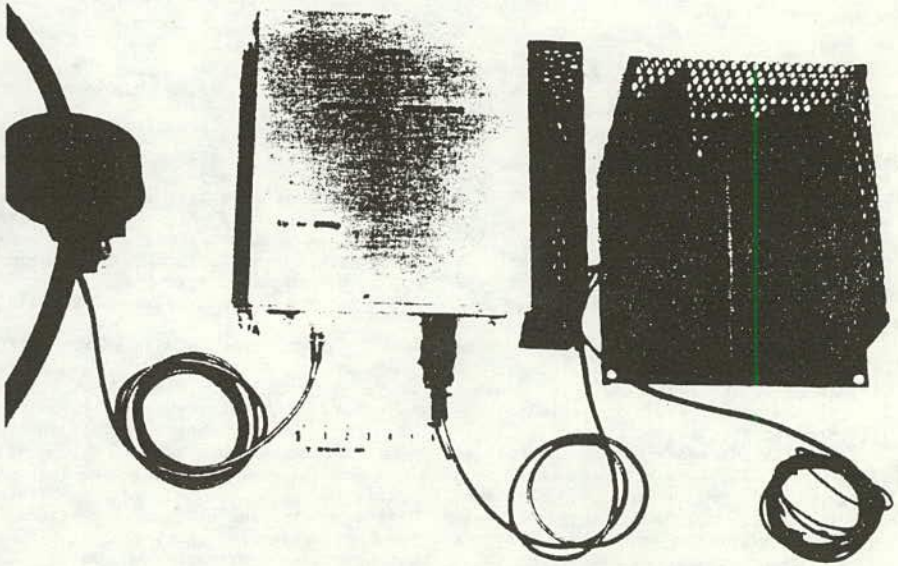

FIGURE 16. - Active impedance multiplier (AIM) with power supply.

Signal currents and voltages were measured with the load at the rectifier. Using the multiplier the current drawn was 1.3 A. Without it current increased to 2.5 A. The voltage at remote points remained unchanged.

Moving the locomotive to point A the current level was not changed by the multiplier's exclusion. However, the voltage decreased from 5.0 to 1.0 V. Figure 17 illustrates the effect graphically.

Poor Track Bonding

Poorly maintained or disconnected track bonds will insert an additional impedance in the rail circuit and slightly reduce the 3-kHz voltage measured at remote points. For example, with a poorly bonded track simulated between the rectifier and G, and the 15-ton locomotive at G, there was a 10-pct reduction in the signal voltage at G over the good bonding value.

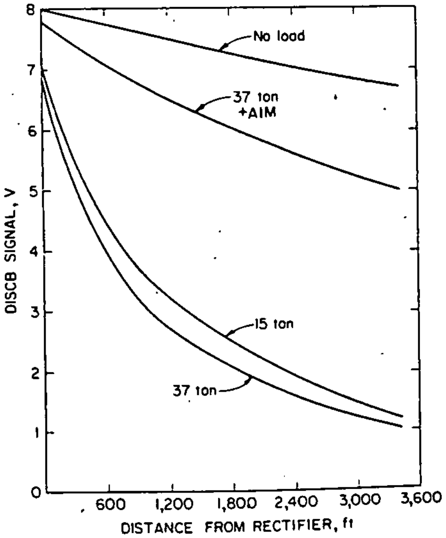

FIGURE 17. - Effects of active impedance multiplier (AIM).

Effects of Arcing

A series of arcing fault tests were conducted to note any effect on DISCB operation. A resistive fault was applied at G in series with two steel electrodes, 0.5 inch in diameter and separated by an air gap. Arcing was initiated by bridging the gap with several strands of a 19-strand No. 12 AWG wire that vaporized upon energization. The air gap was varied from 3/32 to 5/8 in. The presence of the arc did not affect the flow of 3-kHz current or DISCB operation.

Rectified Versus Generated Input

The DISCB and the demonstration board have been used with both a 30-kW generator and a 200-kW rectifier. No difference in operation could be detected. Satisfactory operation was obtained for input voltage fluctuations from 200 to 350 V dc.

Further Study

At present sufficient hardware is available in prototype form for small-scale demonstrations to interested coal operators or for consideration by a manufacturer as a marketable product.

It is intended to install the system at the Federal No. 1 Mine on the portion of rail haulage modeled in the laboratory. Technical advice will be furnished by the Bureau as required throughout the installation and initial demonstration phases of the single-section system. The equipment will remain installed for a sufficient time to accumulate an extended performance history. The Bureau intent is to show that the unit can be operated for a 3-month period with no more than one nuisance interruption and no instance of any failure permitting the trolley line to remain energized for a sustained ground fault greater than 200 A.

Typical trolley haulage systems in coal mines are powered by multiple dc sources, typically about 1 mile apart. The 3-kHz DISCB signal is impressed upon the system at these substations through an oscillator and power amplifier. Since the signal can be applied at several separate locations, means is provided to minimize circulating audio frequency currents by selection of a master frequency and phase. The power amplifier contains a synchronizing unit that locks onto the nearest outby oscillator and disengages its own master oscillator. If for any reason the outermost master oscillator controlling the system is unavailable the next outby oscillator automatically takes over the master role and sets the frequency and phase of the 3-kHz voltages. By this means the integrity of the discriminating system is maintained even when several substations are out of commission. It is this interaction of DISCB power source controls that remains to be demonstrated in the Bureau's laboratory with a multisource system.

Upon agreement with a cooperating mine, the DISCB system will be installed to protect a haulage system having at least three branches protected by separate circuit breakers and fed from more than one dc source. This larger demonstration and long-term usage test will prove to the mining industry that the system is fail-safe, reliable, and effective.

The present design requires that a lightweight cable comprising three twisted pairs of insulated 20 gage wire be strung alongside the trolley wire to carry signals for the system. For the substation breaker to close, proper data must be received through the cable. For example if the cable is broken by a roof fall the dc power cannot be energized. Also, if the detector units indicate a faulty condition, both inby and outby breakers are prevented from closing. The pilot wire carries signals to synchronize the master oscillators and provides the power to operate relays contained in the voltage detectors. Finally, it can be used to reintroduce the high frequency tone onto the trolley at points remote from the substation. Thus, the wire serves a number of vital functions. However, it does require additional labor expenditures for installation and maintenance. So it is desirable to explore substitute techniques, such as multiplexing, to eliminate the pilot wire.

As the 3-kHz voltages and currents are present on the system even when dc power is interrupted it is possible to detect the location of a fault by walking along the wire with ac voltmeter and noting where a minimum occurs. It appears feasible that the fault location can be pinpointed automatically by sampling data from the current and voltage detectors. Ultimately, this information could be fed into a computerized mine monitoring system for readout on the surface.

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APPENDIX F

TECHNICAL DATA FOR DEVICES BEING USED IN TRACTION POWER SYSTEMS AND ON-BOARD ROLLING STOCK

DEVICES BEING USED IN TRACTION POWER (TP) SYSTEM

Impulse Coil and Polarized Instantaneous Relay (*1*)

General

This is one of the oldest systems noticed still being used by some transit systems in the United States, Canada, and elsewhere. It operates on the rate-of-rise of current principle.

Construction

Impulse coil is normally provided on each feeder breaker. The coil primary current is the feeder current, but the secondary output only appears when the primary current is changing. The output is proportional to the change in current and rate-of-rise of current, but not to the total current except when the coil reaches the saturation point.

The output of the coil is fed into a moving coil device which acts as a d'Arsonval galvanometer and then to a polarized instantaneous relay. The moving-coil device responds to any pulse passing through, while the polarized relay responds instantaneously to rate-of-rise of the primary current.

Application

Although there are reports of this device operating satisfactorily in some systems, certain aspects limit the close setting discriminating feature and hence its wide application. Some of these are:

- The moving coil device tends to operate on the envelope of the notches of the starting current instead of discriminating it from the increasing fault current.
- The false tripping can occur as the moving coil relay responds violently to negative rate-of-rise at train notch-off, followed by upscale rebounds.
- Armature movement can be affected by dirt, bearing friction, and attracted iron or steel slivers.

Rate-of-Rise Relay (*10*)

General

The relay is being used with a dc main and feeder circuit breaker to isolate the faulty section of the TP distribution system consisting of either catenary or contact rail. It is usually mounted on metalclad switchgear or switchboards and operates in conjunction with standard shunts. For maximum selectivity between track faults and train starts, the response of the device is very close to the rate-of-rise of the current. The device is capable of instantaneously resetting between the notches of train-starting current or, like a galvanometer, tends to operate on the envelope of the notches, as the envelope can have a time constant of the fault network.

The relay components measure the output of the shunt, and compare it to the preset tripping levels. When an abnormal condition is detected, the relay closes its contacts to energize the shunt trip coil of the circuit breaker.

Construction

Figure F-1 is a block diagram of the relay. The device consists of a transducer around the primary of the feeder circuit breaker, an amplifier, and a "rate" circuit (which is made of a low-pass filter and a derivative circuit designed to provide a compromise between the conflicting requirements of instantaneous response and rejection of the rectifier ripple). A level detector (LD) determines whether the output of the rate circuit is high enough and finally, a time-delay circuit (TD) operates if the rate has persisted above the LD setting for longer than the TD setting.

The relay is available in semi-flush drawout case, with the connection terminals at the rear of the case, while the controls for setting are in the front for the pickup DI and time T.

Application

The application of the rate-or-rise detector is determined

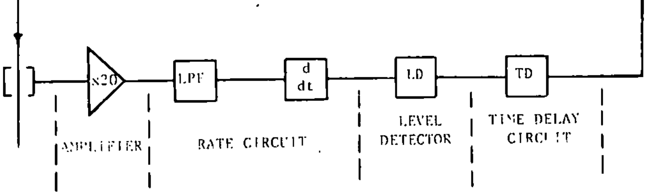


Figure F-1. Block diagram for rate-of-rise relay (ITE-76) (10).

based on calculated fault current using the system parameters, operational constraints and comparing it to the maximum load current.

The simplified formula to calculate the approximate value of fault current can be given as:

$$I_f = \frac{E_s - E_{arc}}{r_1 x} \text{ amps} \qquad \text{(F-1)}$$

where

I_f = fault current, amps;
E_s = system voltage, volts;
E_{arc} = voltage drop access arc, volts;
r_1 = track resistance, ohms per mile; and
x = longest track section, miles.

The value of I_f obtained here is compared to a load current, $I\ell$, in the worst situation of operation. The rate-of-rise device is required in the cases where $I\ell$ is greater than I_f.

The actual reach of any rate-of-rise device can be calculated from the Eq. F-2 once the time delay setting, T, and rate setting, DI, are known.

$$x = \frac{E_s - E_{arc}}{\ell \cdot (DI)} e^{-T/TC} \text{ miles} \qquad \text{(F-2)}$$

where

ℓ = system inductance, milihenry/mile;
DI = selected rate setting of the relay, KA/sec;
T = time setting of time-delay circuit of the relay, sec; and
TC = time constant of the system, seconds;
= ℓ/r of the system.

Settings for the relays can be fixed several ways as both T and DI can determine the reach. It is reported that it is good practice to first assume DI setting and then calculate time setting as follows:

$$T = TC \log_n \left[\frac{I_f}{TC} \cdot \frac{1}{DI}\right] \text{ sec}$$

and keep modifying until satisfactory for respective field conditions.

The rate-of-rise device is stated being used to overcome the problems associated with overcurrent devices. It is reported that in most cases protection can be provided against faults in the remote section.

Voltage Sensing Pilot Wire Relaying (*9, 16*)

General

Basically in this scheme the discrimination is achieved by differentiating between normal train operating voltages and low voltages provided by faults. Here the pilot wires are used between adjacent substations with undervoltage relays in the center and at each end of the feeder section. The undervoltage relay is normally set at 10 percent to 20 percent below the value at which the train undervoltage device operates (which is approximately 60 percent of system voltage). For the double-end fed section, if the undervoltage relay at both ends has a reach of say more than 50 percent of the section, the midpoint undervoltage relay can be avoided.

The system was not intended to be very fast, therefore transient conditions need not be a concern. Inductance and rate of change of current can be ignored. It is also essential that a delay be introduced into the trip initiation circuit such that undervoltage relays do not trip out all feeders in the case of a full short circuit on one feeder greatly reducing the voltage of the entire substation.

The General Electric Co. of England, a manufacturer who encourages the application of such detection devices, claims that the device is sensitive to arcing faults, such that it can differentiate them between adjacent track sections. The protection can be automatically extended to the next zone in case of a substation outage in addition to the feasibility of adding "broken conductor" protection for the catenary system. The device is fail-safe if pilot wires circuit failed; nevertheless, it can be proven to be slightly expensive because of the installation of pilot wires along the right-of-way.

Construction

Figure F-2 shows the simplified pilot wire protection scheme for double-end fed track sections. It also shows the connections required for installing the undervoltage relays ㉗ at each substation location, as well as at the midpoint of the section. The relay control schematic and pilot wire control schematic normally follow steps like energizing, track fault detection, closing on the fault and possibly zone extension.

Application

When the track sections are double-end fed, an undervoltage relay is required at each end, with a common two-wire pilot circuit connecting the undervoltage relay contacts in series to trip the circuit breakers at each end. Because of the very low source impedance, only faults occurring very close to the substations will cause the undervoltage relays to drop out when both circuit breakers are closed. It is therefore essential for the circuit breaker overcurrent trip to cover more than 50 percent of the track section, so that for all faults there will be a single-ended overcurrent trip at the end nearest the fault, followed by an undervoltage trip at the other end, when the system becomes single-end fed. The maximum total length of track that can be adequately protected by this arrangement is twice the maximum distance at which a fault will cause operation of the circuit breaker overcurrent trip, given by

$$L_{max} = \frac{2}{\Omega}\left[\frac{V_s - V_f}{I_{oc}} - R_s\right] \text{ miles} \qquad \text{(F-3)}$$

where

V_s = source voltage, volts;
Ω = resistance of contact rail, ohms/mile;
R_s = source impedance, ohms;

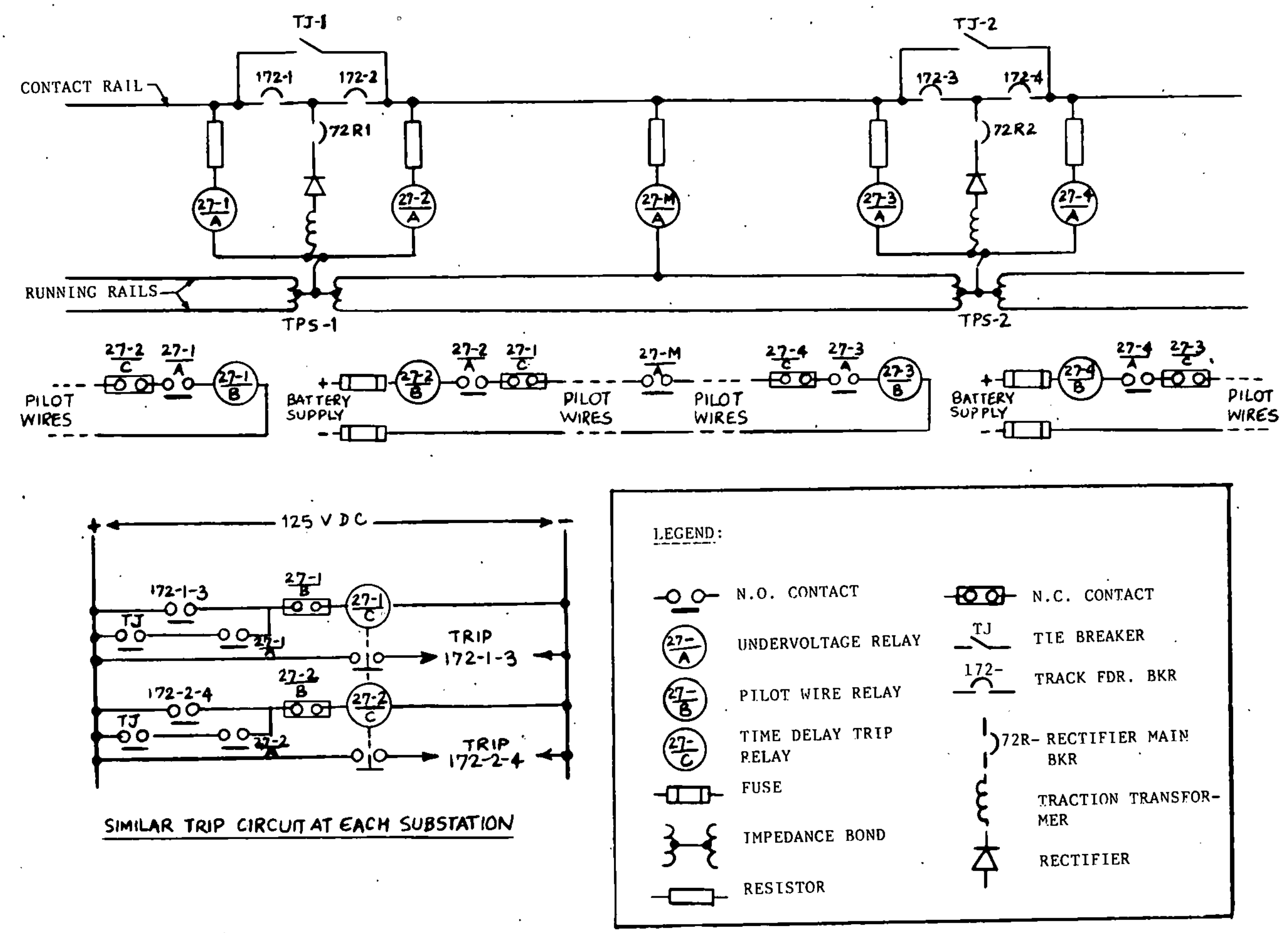


Figure F-2. Simplified pilot wire protection scheme (9).

V_f = maximum expected voltage drop across fault or arc, volts; and

I_{oc} = setting of circuit breaker overcurrent trip, amps.

Track sections longer than L_{max} may be protected by midpoint undervoltage relay for the fault near the center of the section.

1. The minimum fault current which must flow for a fault at the center of the section to cause the midpoint undervoltage relay, set at 0.5 V_s, to drop out, can be given by:

$$I_{MP} = \frac{2\ V_s\ (1.0 - 0.5)}{R_S + \frac{\Omega L}{2}} \text{ amps} \qquad \text{(F-4)}$$

where L is the total length of the track section in miles.

2. The maximum starting current which can be drawn at the center of the section without causing operation of the undervoltage trip on the railcar, set at $0.6V_s$, to operate, can be given by:

$$I_{ST} = \frac{2\ V_S\ (1.0 - 0.6)}{R_S + \frac{\Omega L}{2}} \text{ amps} \qquad \text{(F-5)}$$

Exceptionally long track sections, longer than 2 L_{max} values for which the reach of the circuit breaker overcurrent trip is less than 25 percent of the total track length, may be adequately protected by adding two quarter-point undervoltage relays at points 25 percent and 75 percent along the track section.

Figure F-3 shows the maximum voltage drop across the fault or arc for the track sections near the substations as well as for mid- and quarter-track sections. It seems that only the sensitivity of clearing fault of a midpoint undervoltage relay alone for faults on sections nearer to substations tend to weaken (see points A and B). The sensitivity can be strengthened if the quarter-point relays are used.

When a short circuit occurs closer to a substation the undervoltage relays on all track ends near that substation may detect the voltage dip. Therefore the undervoltage protection is arranged to delay trip initiation by approximately 1 sec to allow the appropriate circuit breaker to be tripped by its overcurrent trip. In the systems with contact rail for faults remote from a substation, the undervoltage relays will discriminate correctly because the contact rail impedance is high compared to the source impedance. Normally in the systems with a catenary, often the broken wire protection (not shorted to ground) is noticed being provided using a pilot wire circuit. The weight-tensioning device is usually designed to connect at the ends of the catenary conductor such that if a conductor breaks, one or

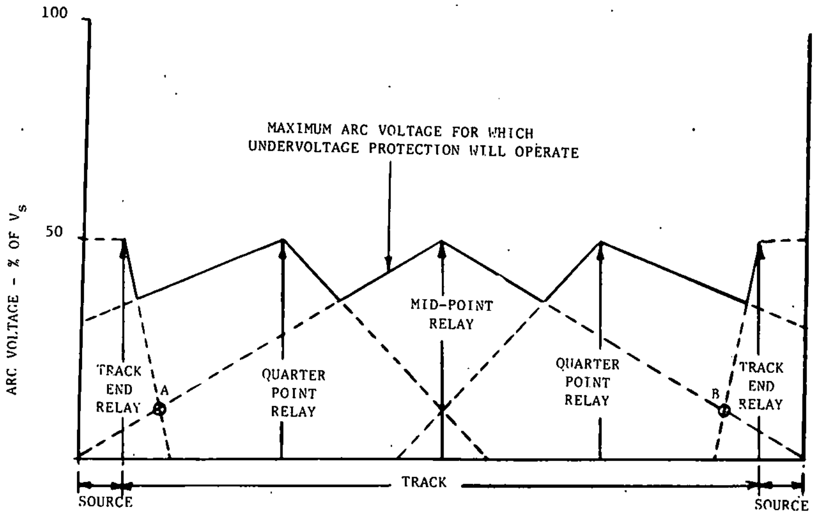


Figure F-3. Sensitivity curves for undervoltage relays (9).

more of the weights will move. The movement of the weight(s) will cause associated limit switches to open. As the limit switches are connected in series with the pilot wire circuit, the opening of the switches breaks the pilot circuit, thereby initiating a trip in the respective feeder circuit breaker.

The undervoltage relays can also be connected such that if a substation is taken out of service, the act of closing the tie-breaker to bypass the substation automatically modifies the protection circuit. The track-end relays at the affected substation act together as a midpoint relay for the two track sections, and the midpoint relays on the connected sections act as quarter-point relays.

DI/Dt Electronic Devices

Unlike commonly used electromechanical devices, the electronic devices working on the di/dt principle became popular in the late sixties or early seventies and were predominantly offered by European manufacturers.

PCC-67 Device (5)

General. BBC-Sécheron developed this device in 1973 for its application in rapid transit lines. It measures the rate-of-rise of feeder current and analyzes with an increased precision. The device is claimed to be highly sensitive to fault and can monitor several motor groups of cars in a train regardless of their switching arrangements. With supplementary on-board fault detecting devices, the PCC-67 was reported to be detecting on-board LCF's as well. With the state-of-the-art developments (to encourage the use of the latest state-of-the-art fault detector, BBC-Sécheron has provided a very limited product description of the PCC-67 device), BBC-Sécheron has launched a more advanced, solid state and compact fault detector which is claimed to be very cost-effective. This fault detector is discussed later in this section of the report.

Construction. The device consists of three major components:

1. Electronic cabinet containing three potentiometers respectively for adjustments of pickup, dropout and surface value, one cyclometer dial for digital indication of time delay, test switch and indicating lights.
2. Electromagnetic current coupler consisting of multiple air-gap magnetic circuits to be mounted on the positive bus or on the positive cables. The voltage proportional to di/dt of the feeder current can be obtained at the secondary of the winding.
3. A voltage coupler connected to the positive and negative rectifier terminals by a high voltage cable. It gathers the voltage waveform information at the rectifier terminals.

Figure F-4 is a block diagram of the PCC-67 relay, and Figure F-5 shows the completely assembled PCC device with the door open.

Application. There are reports of one PCC-67 per traction power substation being used for monitoring four negative contactors successfully initially, and later on sharing four dc positive feeder breakers. The operation of the device can be classified in basic detection, detection of superposition, comparison of a signal furnished by the electromagnetic coupler and of a signal simulated from ordinary traffic, saturation and pulsating shorts.

Basic detection is comprised of a voltage output from an electromagnetic coupler due to the di/dt of the current. The output after getting compensated is measured by two voltage level detectors, one activates and the other deactivates the clock. If the time, measured digitally by this clock exceeds the set value of the time delay dials, the device trips the feeder breaker.

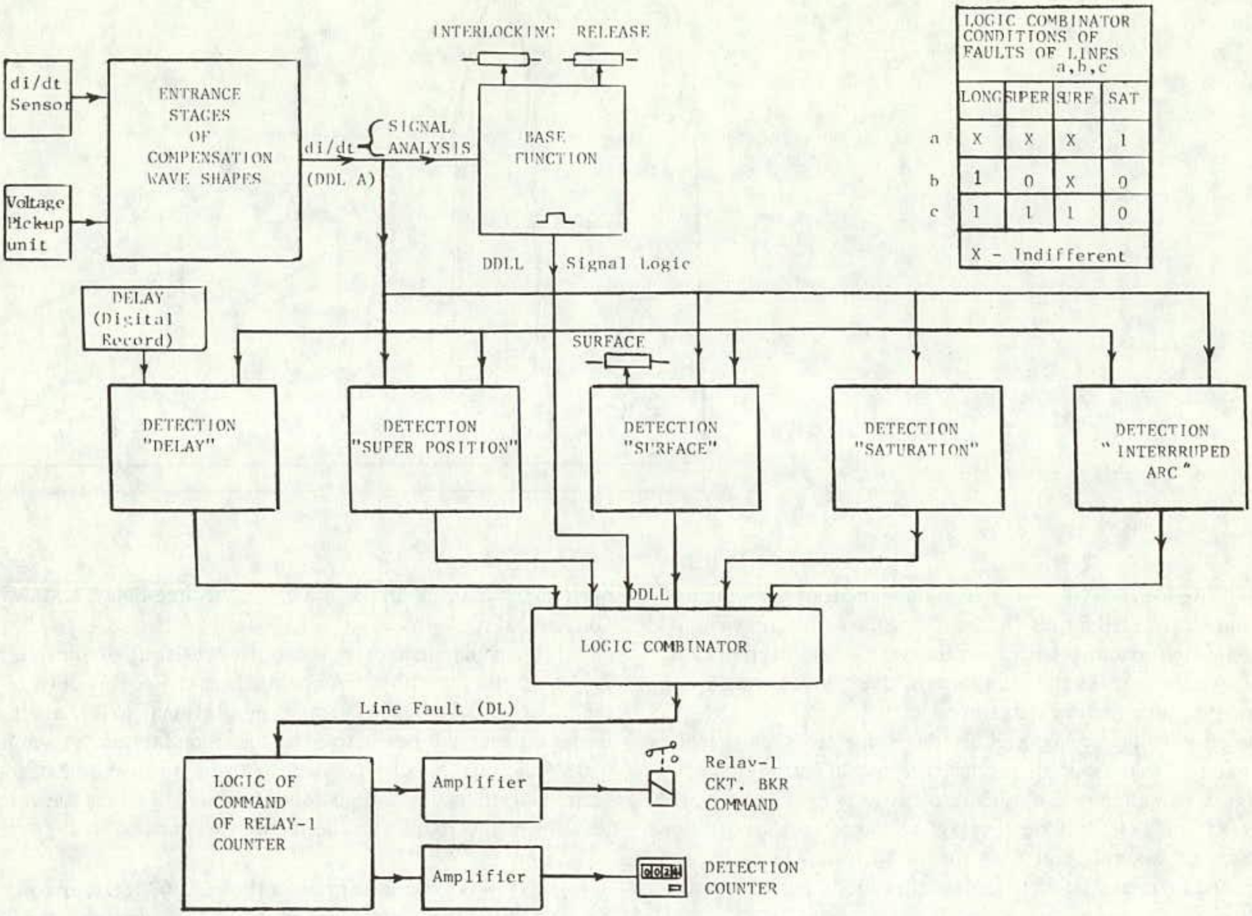
If a di/dt signal from the coupler gets superimposed by similar other signals from the same coupler, a possible nuisance trip order could get generated unless the superimposed signal exceeds the value of the "Super-position" dial, in which case after its registration, the breaker trips appropriately.

The "Saturation" function is responsible for a low-current fault nearer to the substation, while the "Pulsating Shorts" take care of high resistance or arcing faults.

The firm claims that the PCC-67 device installed at TPS also detects onboard faults.

Rate-of-Rise of Current Trip Assembly (14)

General. The current transformer senses the rate-of-rise of



LOGIC COMBINATOR CONDITIONS OF FAULTS OF LINES a,b,c

	LONG	SUPER	SURF.	SAT
a	X	X	X	1
b	1	0	X	0
c	1	1	1	0

X - Indifferent

Figure F-4. Block diagram of PCC-67aE device.

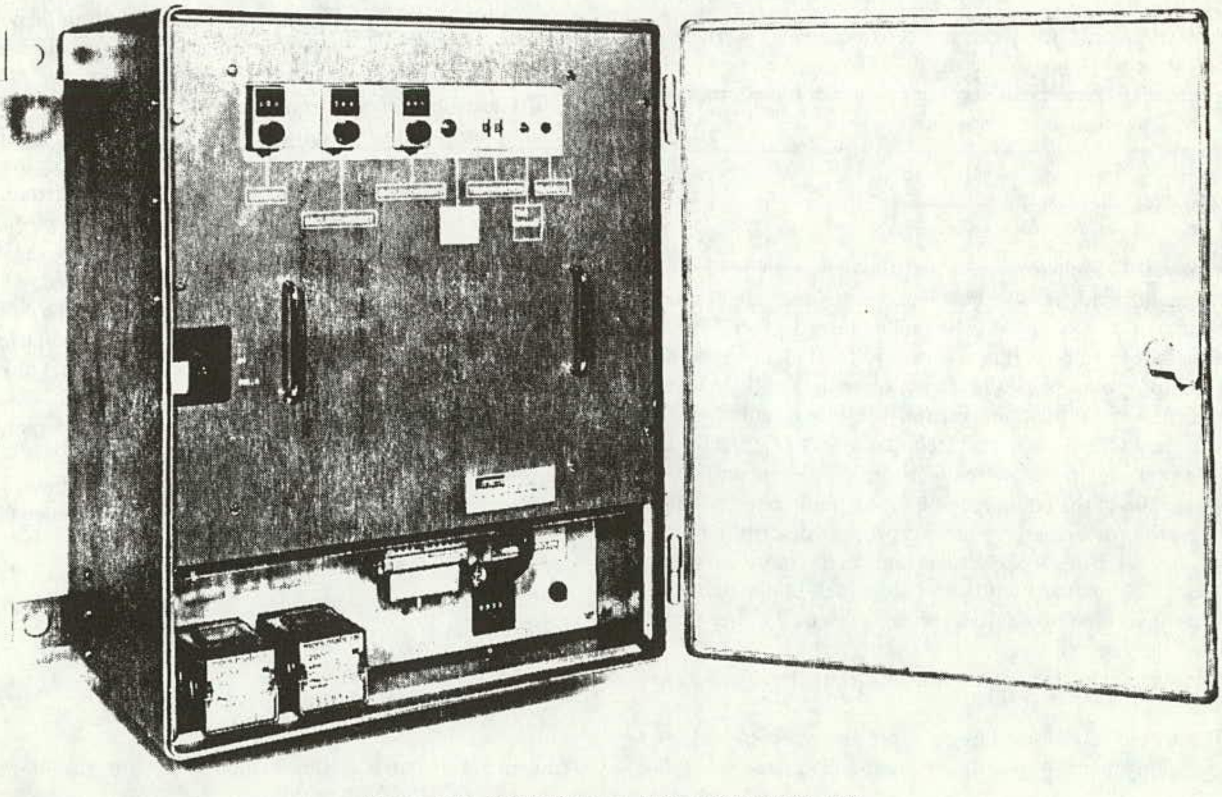


Figure F-5. BBC-Sécheron device PCC-67 (5, 12).

current which is being fed to the rate-of-rise of current trip assembly. Siemens and Siemens-Allis offers these devices in conjunction with its high-speed circuit breakers. The release is able to sense a fault at a very early stage, thus initiating the tripping of the high-speed breaker before the current equals the setting of the breaker's conventional electromagnetic release. In conjunction with the exceptionally short operating time of the breaker, this feature reduces the fault current peak still further. The release also senses distant and low-current faults. The tripping sensitivity of the relay is adjustable and can be matched to specific applications.

Construction. The device consists of a current transformer, a tripping unit, and a capacitor controlled release. The four basic modules with their functions are:

u1	Power supply
u⅔	Charging voltage and thyristor triggering
u4	Evaluation
u5	Display and trip register

All of the terminals are connected to a block that is accessible from the front. The tripping sensitivity can be adjusted on the potentiometers in the fascia strip of module 4 when the cover is opened.

The capacitor-controlled release, which is of the high-speed open-circuit type, is fed from the capacitors in the tripping unit on triggering of a thyristor. It forms an integral part of the breaker and acts directly on its latching mechanism.

Figure F-6 shows the front view and connection block diagram for the device.

Application. Module u1 supplies the tripping unit power; module u⅔ produces the voltage required to charge the capacitor. When module u4 senses a fault, while analyzing the current transformer output, the thyristor fires and capacitors are discharged through a coil of capacitor-controlled release and trips the breaker instantly. In general, module u4 covers the following functions: instantaneous tripping, delayed tripping, directional sensitivity, speed of response, and transformer circuit discontinuity monitoring.

The instantaneous trip is for early detection and the quickest possible clearing of faults by limiting the short-circuit I^2t value. Instantaneous tripping is based on the measurement of current surges, ΔI, and its rate of increase di/dt against the preset value. The instantaneous trip covers the nearby faults, while the delayed tripping covers the distant faults by the continuous increase in current at a low rate-of-rise. The directional sensitivity feature allows the device to trip the breaker nearest to the fault only in the forward direction. Depending on the single-end-fed or double-end-fed system as preferred by the operating agency, the trip inhibition can be changed from no trip inhibition, or voltage-dependent trip inhibition, to trip inhibition on closing. The device also senses and trips breaker for the condition of a broken wire in transformer measuring circuits.

In order to set the relay properly, the setting ΔI, di/dt, and t shall first be determined based on the system descriptors.

- *ΔI Setting*. The ΔI setting is determined based on the maximum current surge value ΔI_{max} calculated as follows:

$$\Delta I_{max} = \left(\frac{n\ V_{rs}}{R_{s/p}}\right) 10^{-3}\ \text{kA} \qquad \text{(F-6a)}$$

or

$$\Delta I_{max} = \frac{c}{2}\ I_p\ 10^{-3}\ \text{kA} \qquad \text{(F-6b)}$$

or

$$\Delta I_{max} = c\ I_s\ 10^{-3}\ \text{kA} \qquad \text{(F-6c)}$$

where

$R_{s/p}$ = resistance, in ohms, parallel to the series connected motors at changeover (from series to parallel operation in cars);
n = number of $R_{s/p}$ resistances per longest train;
V_{rs} = rated voltage at the substations $\cong$ 1.1 times the rated vehicle voltage;
c = number of cars/train;
I_p = maximum current/car during parallel operation at starting, amps; and
I_s = maximum current/car during series operation at starting, amps.

It is customary to select the next higher standard rating on the ΔI dial of the ΔI_{max} calculated value.

- *di/dt Sensitivity Setting*. The di/dt sets the lowest rate-of-rise to which the release will respond, and it can be obtained by:

$$\frac{di}{dt} = \frac{0.7\ V_{rs}}{1.1\ L} \cdot e^{-\left(\frac{1.15 \Delta I_{max}}{I_k}\right)}\ \text{amps/sec} \qquad \text{(F-7)}$$

where

I_k = prospective fault current, in kA, and can be obtained from the oscillogram of a short circuit at the most remote point to be interpreted by delayed tripping or analytically by $I_k = \frac{V_{rs}}{\ell \cdot (R_1 + R_2)}$ kA, in which ℓ is the section length in miles, R_1 is the resistance of contact rail section in ohms per mile, and R_2 is the equivalent resistance of running rails in ohms per mile;
L = inductance of faulted network in mH from the same oscillogram or using $L = \frac{V_{rs}}{(di/dt)_o}$ mH, in which $(di/dt)_o$ is the initial rate-of-rise of faulted current, in amps/msec, obtained by tangent at time t = o.

- Delay Time t Setting. If the di/dt setting value as calculated above is within the range of di/dt setting, the t setting can be given as:

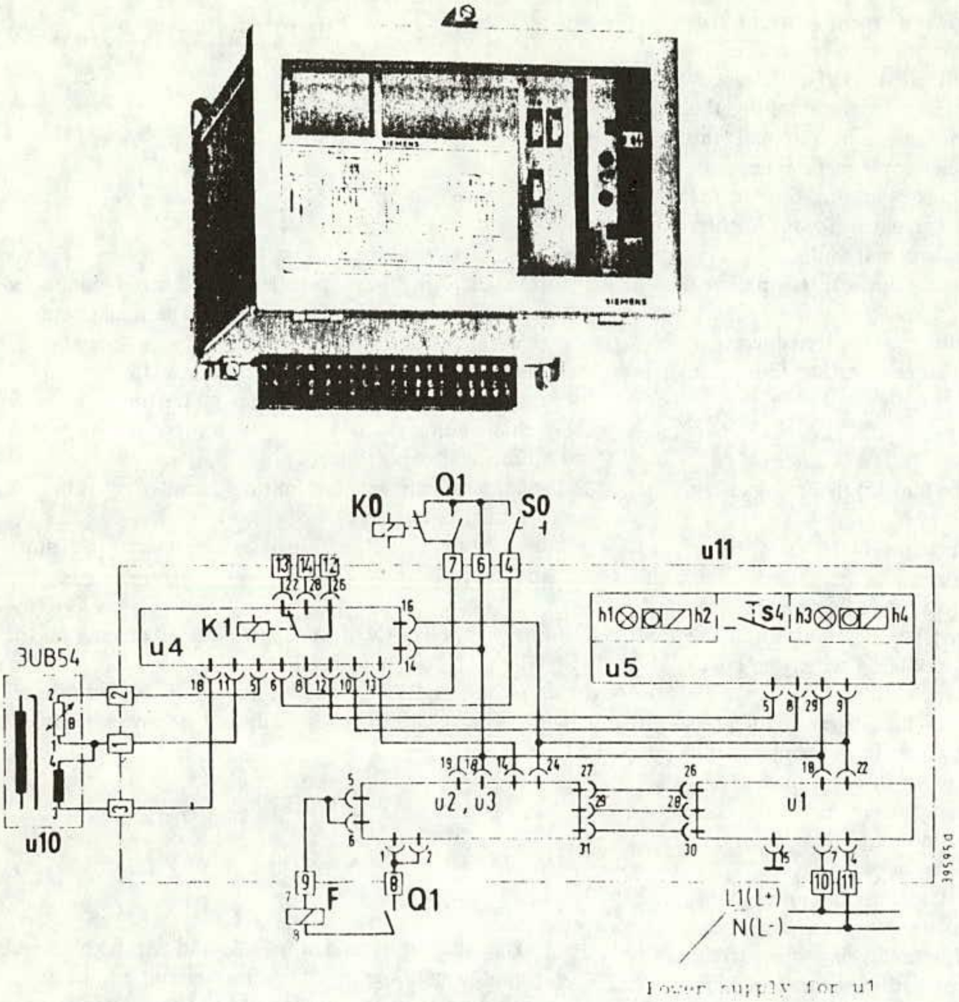
$$t = \frac{1150\ \Delta I\ L}{V_{rs}}\ \text{msec} \qquad \text{(F-8)}$$

Otherwise, the following Eq. F-9 can be used:

$$t = \frac{1000\ L}{V_{rs}}\ \frac{I_k \Delta I}{I_k + \Delta I} \left[-\log_n \frac{15L}{V_{rs}}\right] \text{msec} \qquad \text{(F-9)}$$

DCC-78 Device (4)

This is another device reported being used by a few transit



Q1	High-speed DC breaker
F	Capacitor controlled release
S0	Test key
S4	Resetting
K0	Voltage monitoring (trip inhibition, required only for traction systems)
K1	Signalling/tripping relay
v1,2	3 sensitivity setters
u1	Power supply
U2/3	Charging voltage and thyristor triggering
u4	Evaluation (delayed/instantaneous tripping)
u5	Display and trip register
u10	Current transformer 3UB54
u11	Tripping unit 3UB51

Figure F-6. Front view and connection block diagram of Siemens 3UB Rate-of-Rise Trip Assembly (14).

systems overseas. It is also an electronic device, though less complicated in operation and setting, manufactured by Société CERME of France. Despite numerous requests, the manufacturer failed to furnish the Product Information to the Project. Also, not enough data were furnished by the two overseas systems reported using this device, and hence the discussion is limited to such an extent in this report.

Δi Electronic Devices

The other set of devices reported being used are the electronic devices working on the amplitude and waveshapes of each current increase Δi in the feeder continuously and comparing it for preset values of Δi and time setting to discriminate the fault current.

Electronic Line Fault Detectors (8, 12)

General. In 1978, BBC-Sécheron developed an electronic line fault detector, DDL-ACA-11, for a rapid transit system which is reported being used predominantly in overseas transit systems both for metro and light rail. It is also being used successfully with single or MU cars consisting of motor groups or relatively low unit power, having either conventional, cam, or chopper control.

The interesting features are that the device, although mounted in TP substations, detects on-board faults and its operation does not depend on the time constants of the network involved in the fault.

Construction. The complete device consists of a separate measuring amplifier module MIU-5 and three other modular units including the DDL and signalling setting and controlling devices as shown in Figure F-7. Figure F-8 shows the interconnection diagram.

The unit has the capabilities for the testing mode, and has the circuits for fail-safe operation. The unit can exericse temporary blocking of detection and remote control of settings and monitoring of several feeders and feature of time-dealy operation.

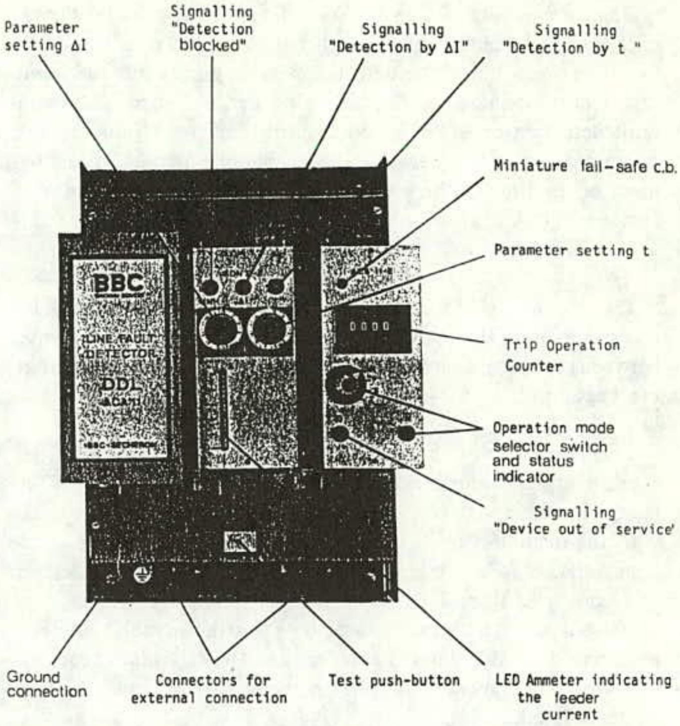


Figure F-7. Elements for setting, signalling and connection of DDL-ACA-11 (12).

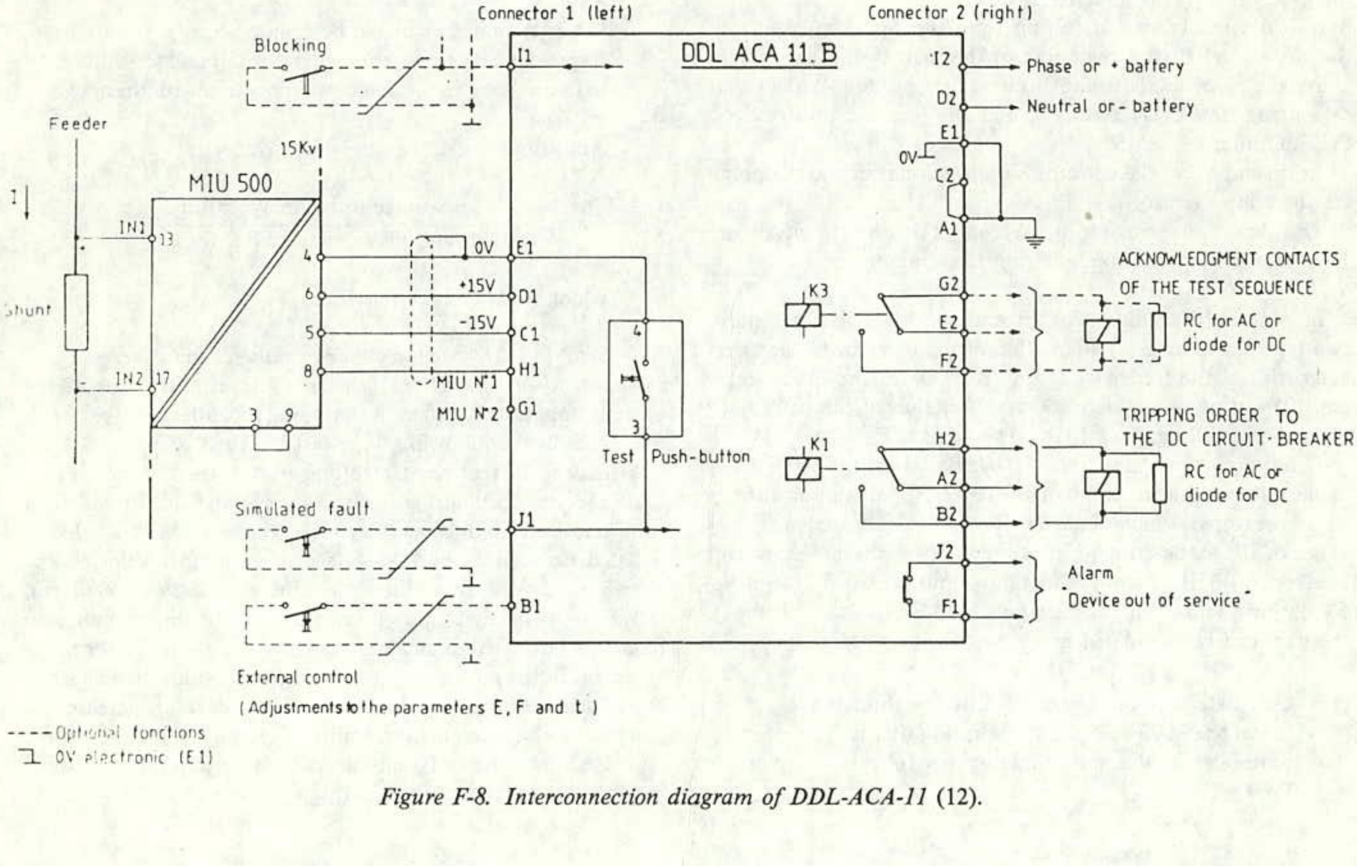


Figure F-8. Interconnection diagram of DDL-ACA-11 (12).

Application. The DDL-ACA-11 device analyzes the feeder current signal transmitted through an isolating measuring amplifier. The operation of the detector is based on the measurement of the current increase, ΔI, occurring in the feeder. The main fault detection criterion is the exceeding of a set value by the measured current increase, ΔI. The complementary measurement of the time of the increase signal enables the detection of remote faults of low amplitude.

It is of interest to consider the tripping criteria in detail:

1. *Detection by the Criteria of the Current Increase, ΔI.* The measurement of the current difference, ΔI, detects the difference between the instantaneous current value and that memorized at the beginning of the increase when the memory is taken offline.

The beginning of the increase is detected when its gradient exceeds a preset slope value. When this slope (known as E) is reached, the input current level is memorized and compared with the instantaneous values of current until the increase gradient falls below a preset threshold, defined as the increase end and known as slope F.

At that time, if the difference between the actual I and the memorized-I has remained smaller than the set value ΔI, there is a rapid reconnection of the memory to the actual system current signal.

On the other hand, if the measured ΔI becomes greater than the set value, the tripping relay K1 of the detector gives the order for the opening of the circuit breaker. This relay falls back after about 1.2 sec and the unit is again ready to carry out another detection.

2. *Detection by the Criteria of the Increase Time, t.* Two criteria are considered for current signals with slow increases (remote line faults): (a) the increase time t, and (b) the minimum increase value M of the current signal.

In order to obtain a detection by t, the signal must exceed the slope level E (the beginning of the increase), must remain above the slope levels E and F for a duration longer than that set on the time-delay setting t, and the increase must exceed the minimum ΔI set, M.

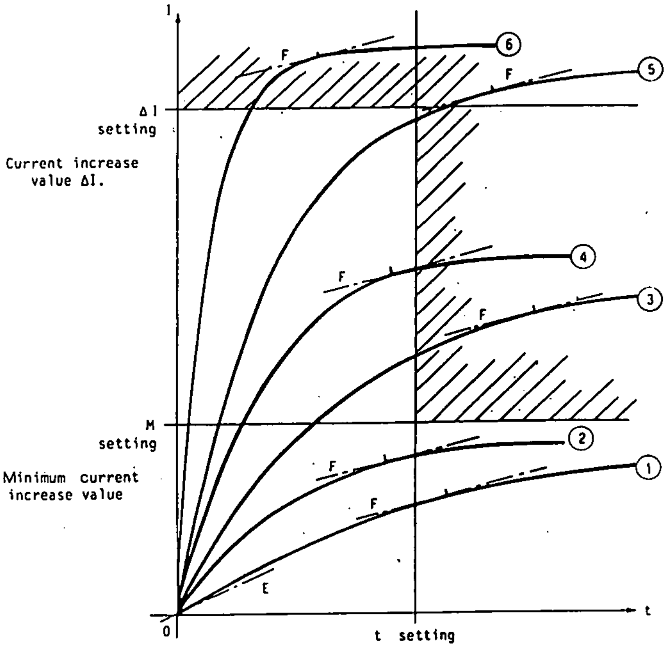
At this moment, the detector initiates circuit-breaker tripping via the tripping relay K1.

The detection principle by ΔI and t is shown on Figure F-9, with the shaded area as being the tripping zone.

In general, the DDL detector and the MIU device require two types of setting: (1) adaptation of the detector to the characteristics of the feeder by setting the gain of the input stage, and (2) setting of the detector as a function of the conditions of load and rolling stock (parameters ΔI, t, E, F, and M).

1. *Setting of the gain (with MIU).* Based on the known: (a) value of the measuring shunt on the feeder, (b) maximum current to be measured which could be flowing in this feeder (I_{max}—value of the static tripping threshold set on the power circuit breaker, (c) MIU transfer function (input 60, 90 or 150 mV/5V output), and (d) input rating of the ACA-B (± 10 V max), the gain can be calculated using the following steps:

- Calculate the voltage supplied by the shunt for I_{max}.
- Select the MIU operation calibration that is the closest to the above value and compute the MIU output voltage for I_{max}.



Curves	Detection by	
	ΔI	t
1		
2		
3		x
4		
5	x	x
6	x	

HATCHED AREA → TRIPPING ZONE

Figure F-9. Detection by ΔI *and* t *of DDL-ACA-11* (12).

- Select the current image best suited, i.e., a good correspondence between the feeder current and the voltage to be analyzed in the detector, in relation with the above criteria.
- And, finally, gain can be given by:

$$\text{Gain} = \frac{\text{Signal voltage to be analyzed for } I_{max}}{\text{Output voltage of the MIU for } I_{max}}$$

which must be between 1 and 2.

2. *Settings of E—the beginning of the current increase and F—the end of the current increase.* The measurement of the current slope is obtained at the output of the differentiator circuit and is set in the following way (test terminal X7).

When the current slope resulting from a traction notch or a fault exceeds the adjusted slope value E, the measurement of time and current increase begins. Generally the set value is situated between 1 and 10 kA/sec. For chopper vehicles, the slope should be set above the highest increase of traction current.

When the current slope produced by a traction notch or a fault reaches a value smaller than the set value F, the measurement of the current increase ΔI and t is stopped. The slope adjustment which determines the end of a current increase is a compromise between the possibility of measuring all the current increases (low value of F) and the ability to discriminate between several closely related notches (high volume of F).

The choice of this setting is thus dependent on the rolling stock characteristics. For conventional cars, the set value for F should allow for an individual analysis of the several notches during the train acceleration. On the contrary, for chopper-controlled cars, theoretically without notches, the setting of the F slope can be lower.

3. *Setting of ΔI.* The setting principle is to select a ΔI value as small as possible while allowing for normal operation of the coaches.

This value is a compromise between the most sensitive protection during the acceleration (which corresponds to a high sensitivity level of the detector) and the acceptance of some nuisance trippings due to the drawing of high currents or perhaps simultaneous train starts.

The average value of the first setting is given by the most significant notch of the traction current. It is not necessary to conduct any short circuit tests in order to set the device. The optimal setting is determined by a statistical method.

This method allows the determination of the lowest setting (highest sensitivity) of the unit relative to the permissible limit of nuisance tripping of the circuit breaker.

First, the following operations need to be performed:

- Set the selector switch (right module) on "statistic" (S).
- Set the E and F potentiometers.
- Set the M potentiometer at "0".
- Set the t potentiometer to the maximum.
- Set the counter to zero.

Then, over a period of several days:

- In a progressive manner, reduce the values for ΔI. The unit must be operational during several hours or days for each setting level. For each of those settings, the number of trippings (counter) should be noted.
- These values should be plotted on a graph with the different set values on the ΔI potentiometer on the x-axis, and the number of trippings per time unit (on a 1 day basis, for example) corresponding to the value set on the ΔI potentiometer on the y-axis.
- A curve can be obtained showing for which value of ΔI nuisance trippings will practically disappear. The heavier part of the curve shows the acceptable range of ΔI settings related to the degree of protection desired, as shown in Figure F-10.

4. *Setting of M.* The parameter M is a complementary function of the t parameter. It has a function of blocking the t parameter to avoid nuisance tripping, which may have resulted because of low-current increase of base load for a long duration with a previous pick-up of E produced by a current jump. It is set first by determining the minimum value of current increase produced by a remote fault and then is based on the recognized (either by calculation or by actual recording) value of current increase and its corresponding value (which may be different) of M.

5. *Setting of t.* It has the function of detection of remote faults where the final current magnitude may not reach the set value of ΔI due to the line resistance, and still less than that of the static threshold of the feeder circuit breaker which has to allow the circulation of the total traction current.

The time between the detection of the beginning of the increase, E, and the detection of the end of the increase, F, is measured. If this time exceeds the value set by the time-delay, t, and if the set value of the ΔI minimum, M, is exceeded, the unit gives a trip command to the circuit breaker.

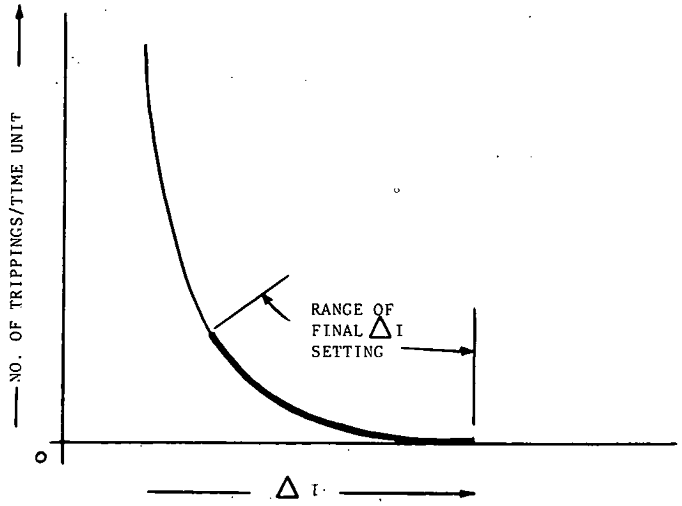


Figure F-10. Statistical method for setting ΔI for DDL-ACA-11 (12).

This setting is also determined using the statistical method, as indicated in Figure F-10, once carrying out the following operations:

- Set the selector switch (right module) to "statistic" (S).
- Set the E, F, and M potentiometers.
- Set the ΔI potentiometer to the maximum (this function is then virtually out of service except for significant faults which would have produced a circuit-breaker trip and which must be deducted from the statistical records).
- Set the counter to zero.

Parameters ΔI, t, E, F, and M should be fine tuned during operation per field conditions.

Fault Selective Device (15)

General. This is also an electronic device working on the current increase principle manufactured by Tsuda Electric Meter Company Ltd. of Japan. The manufacturer claims that about 3500 units are in operation in railroads of Japan, Australia, and India regardless of the current collection system. The device analyzes each current increase to discriminate it from the fault current which is determined by the time constant of the faulted network.

Construction. The fault detector (FD) is a primary conductor penetrate-type transformer with current direction marked on the holding bakelite plate. Inasmuch as the FD has a split construction, it can be mounted around the primary conductor after installation of the primary conductor. The FD has three coils—a main detecting coil (terminals KM, LM), a section compensating coil, and a test coil (terminals T+, T−) as the secondary windings.

The fault selective relay (FSR) is a panel-mount-type device. Three plug-in-type electromagnetic relays (50FA, 50FB, 50FZ), two magnetic counters (30A, 30B), current setting knob, pilot lamp, and power switch are located on the front of the FSR. Relays 50FA and 50FB are used as a command relay to trip the HSCB. These relays reset automatically approximately 0.5 sec after operation. Relay 50FZ changes the sensitivity of this device in the extent of 200 percent of its setting current just before reclosing of the HSCB by connection of terminals S_1 and S_2 instantaneously. Counters 30A and 30B indicate number of operation of this device, and can be reset by a button on the right side of the panel. Inside the dust-proof board, there are three printed circuit (P.C.) boards—two are for the detecting circuit and one is for the integral circuit. These P.C. boards are plug-in type, and to remove them, the power switch should be turned off first.

The input and output terminals are located on the rear side of the FSR. Wiring should be carried out completely adopting the press terminals. A block diagram of the device, together with integral circuit, is shown in Figure F-11.

Application. The device normally monitors two feeders simultaneously. The FD is a primary penetrated-type transformer having a slit in a part of its magnetic path. A detecting coil (W_M), a section compensating coil (W_S), and a test coil (W_T) are located on its magnetic path.

If a short-circuit fault occurs on a feeder line, the current, $i = (E/R)(1 - e^{-\alpha t})$ amps, will flow, and the $-M di/dt$ voltage will be transmitted through the W_M coil of the FD. After the FSR receives this voltage, the I_M (integral circuit) in the FSR changes the waveshape of this voltage. The shape of this wave is similar to the fault current wave if the integral constant comprised of C and R is properly calculated, and the maximum value of this voltage wave is nearly proportional to the ΔI current. Then the output voltage of the I_M applies to the comparator COM. If the comparator input voltage is exceeded by the fixed value, the comparator COM will actuate. Following this procedure, the power amplifier PA amplifies the output voltage of the comparator, and the magnetic relay MR is actuated for a settled time to trip the HSCB. The selective characteristics (di/dt and ΔI characteristics) are determined by the integral constant of I_M which is given by Figure F-12. Normally the section compensation factor is adjusted at 50 percent.

After installation of this device, adjustment of the initial setting should be carried out as follows. First, measure the maximum current of starting train, then set the setting current switch as one-half this starting current without linking with the HSCB. Then, if unnecessary operation is observed, increase the setting value. The interlocking between the fault selective device and the HSCB should be carried out after confirming that unnecessary operation does not occur during a certain period. When the traffic condition is changed, readjustment will be required.

DC Feeder Current Analysis Device (15)

General. This device is reported occasionally as being used in association with the fault selective device already discussed above. The dc feeder current analysis device is mounted in a TP substation to measure the increasing ΔI current of each feeder. The device provides 10 counters and each counter indicates occurrence numbers of the fixed ΔI current by train operation. The device is portable, is of light weight, monitors two feeders simultaneously, and has the ability to change its sensitivity by a selector switch.

Construction. The device consists of two ΔI detecting transformers (CT), and one analysis device (AD) and two lines measurement devices. The analysis device consists of a ΔI detecting circuit, a drive circuit, and five counters per feeder measurement. In addition, it has a power supply and control and sensitivity adjustment devices as shown in a connection block diagram (see Fig. F-13).

Application. The CT output voltage is changed to a similar figure voltage of primary dc current by primary system integrator (IM), and fine comparators actuate if the input voltage is greater than the fixed voltage. Hence, the di/dt ΔI detecting characteristics of this device are similar to the dc feeder fault selective device shown in Figure F-12.

Setting currents are separated five rank and current detecting signals are memorized in memories (M1-M5); the device then steps up the electromagnetic counter (MC1-MC5) through the high rank preference circuit and power amplifier circuit (PA1-PA5). The high rank preference circuit selects the highest rank current in one ΔI current and steps up its rank counter.

When the train notch-up currents flow in the feeder, each counter indicates the aggregate figures of the ΔI currents.

Miscellaneous Detection Devices Reported Being Used in TP Systems

Rate-of-Rise Relay 3R-1A (13)

General. Some transit systems have reported using rate-of-rise relays of type 3R-1A in conjunction with inverse time relays ITR-1A, both offered by General Electric Co. of the United Kingdom. The company claims that the combination of such relays offers the best protection possible.

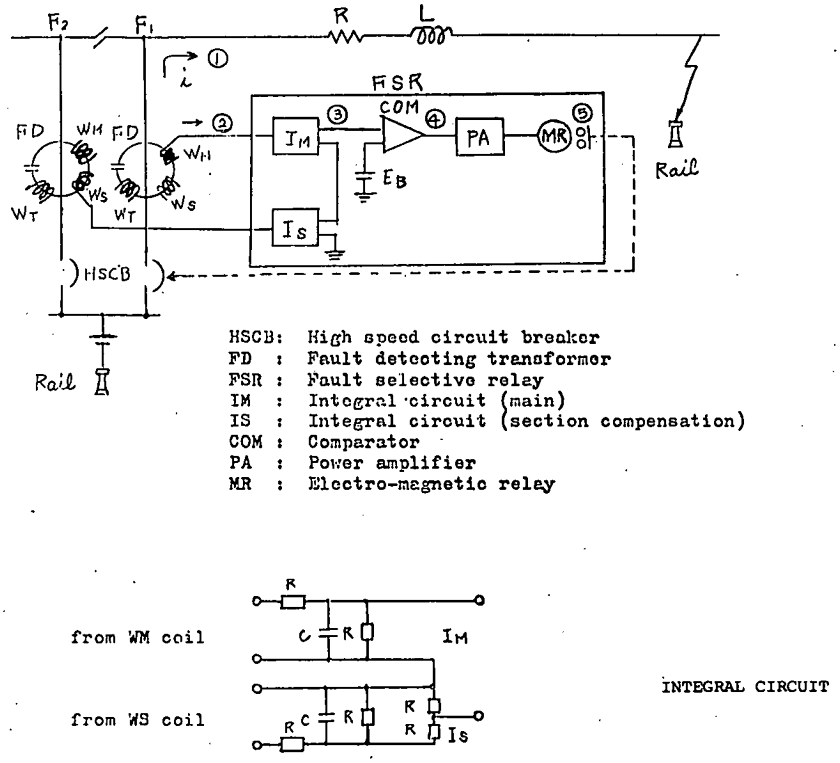
Construction. The relay is housed in a semiflush-mounted case suitable for panel mounting with the provision for connections in the rear. All controls are on the front panel behind the removable clear cover. SUPPLY ON and TRIP indication is visible through the front cover, while a TRIP RESET pushbutton can be operated by an extended actuator button. Parameters can be set by miniature slide switches on the front panel. The TEST pushbutton is also provided on the relay.

Application. The rate-of-rise relay senses a rate-of-rise of current in excess of a preset level, while the inverse time relay can be set to trip at a relatively low level of current, i.e., persists, for a preset period of time. The rate-of-rise relay trips early and minimizes the possible damage caused by long-term arcing.

Unbalanced Current Protection (UCP) (17)

General. This is a very interesting low-current fault detecting device designed and presently in use by London Transport Executive (LTE) System, in England. The device is designed for an LTE system which consists of separate positive and negative contact rails in addition to two running rails (which are neither bonded to earth nor deliberately insulated from earth). The two contact rails are also insulated from earth and the running rails.

Under normal conditions, the positive and negative currents of the dc supply are equal in magnitude and opposite in polarity at the points of supply. In the event of complementary earth faults occurring, it has been established that the balance of the



HSCB: High speed circuit breaker
FD : Fault detecting transformer
FSR : Fault selective relay
IM : Integral circuit (main)
IS : Integral circuit (section compensation)
COM : Comparator
PA : Power amplifier
MR : Electro-magnetic relay

Figure F-11. Block diagram and integral circuit of the fault selective device (15).

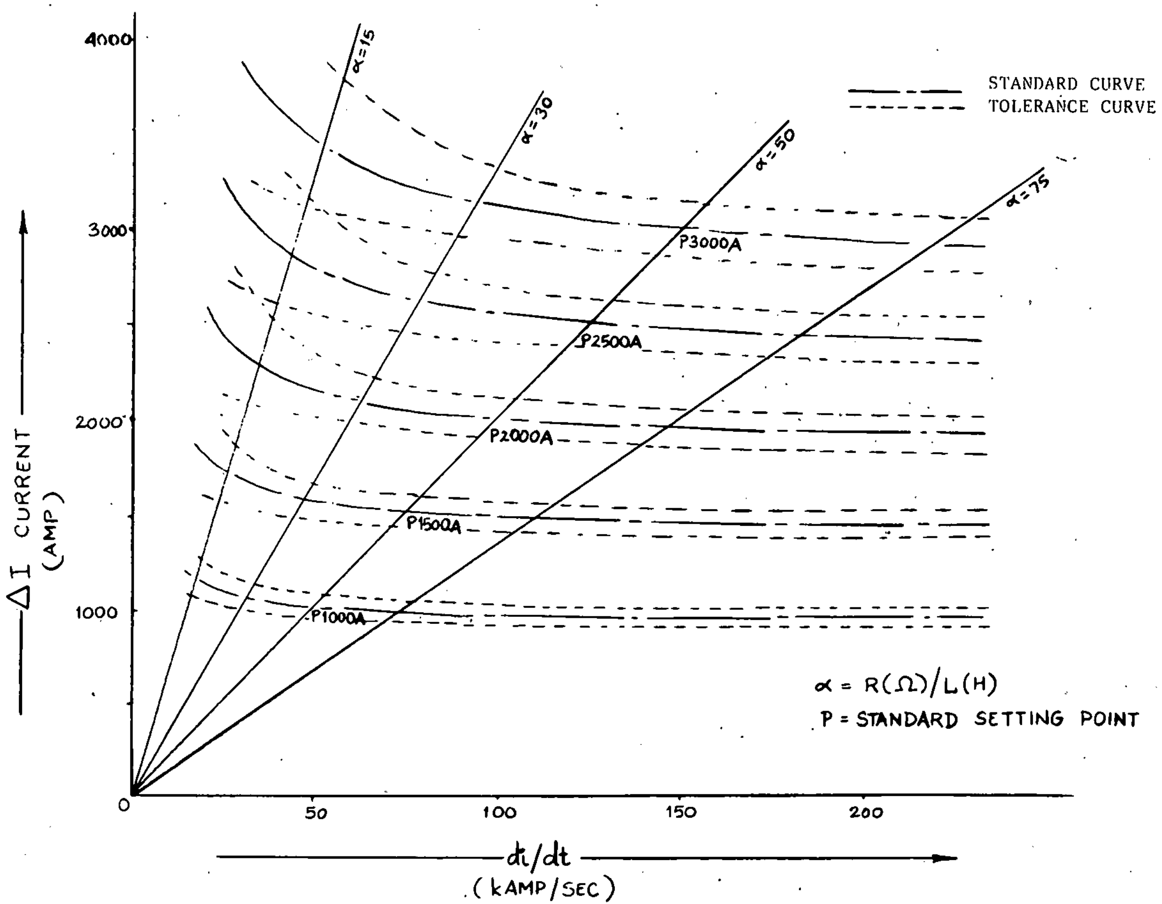


Figure F-12. The di/dt *and* ΔI *characteristics of the fault selective device* (15).

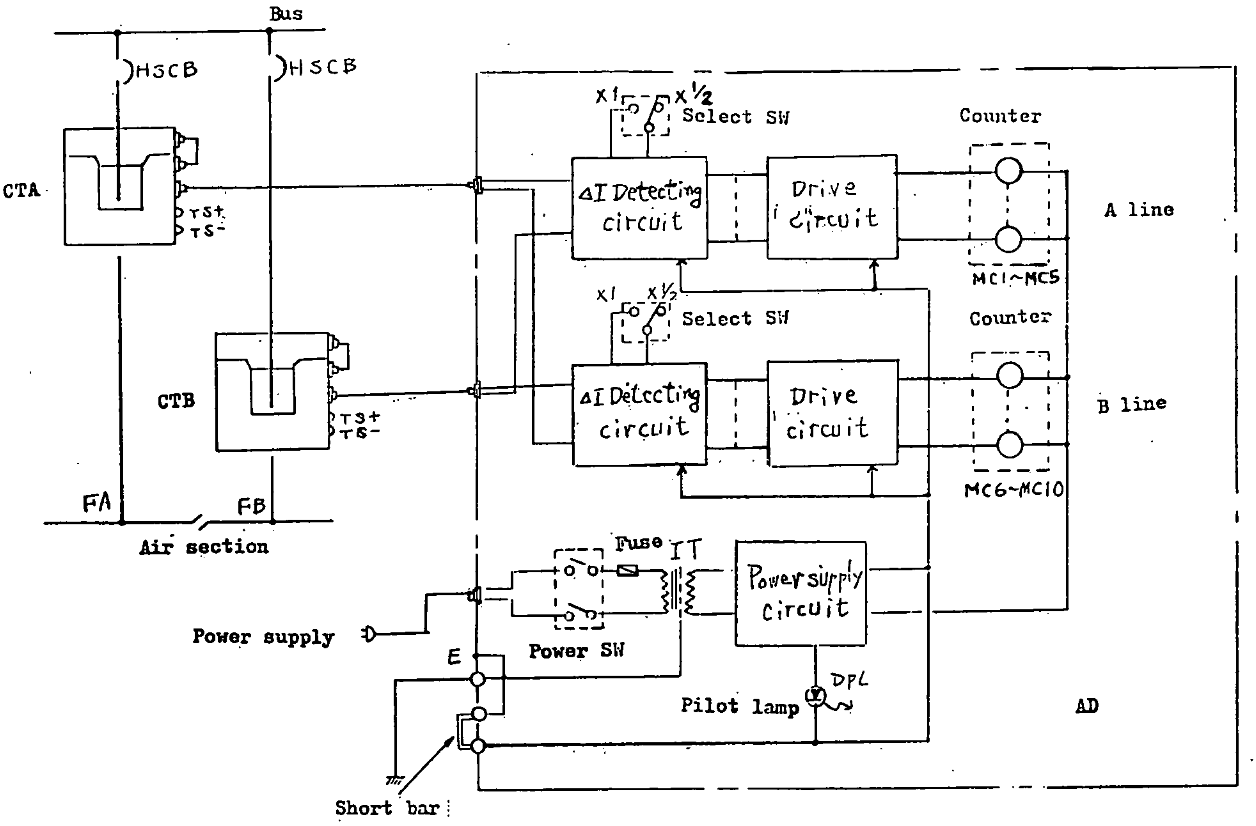


Figure F-13. Connection block diagram of dc feeder current analysis device (15).

positive and negative currents gets disrupted, and it is this unbalanced condition that the UCP device is designed to detect.

Under these fault conditions, an unbalance of current will occur, irrespective of any load current supplied. However, the actual value of unbalance can be relatively low because the faults are usually limited either by the nature of the fault or, in the case of arcing, by the resistance of the arc itself.

Construction. The UCP equipment for each track section consists of four complete units, one for each feed to the section. Each unit consists of two iron-cored toroids, one on each cable from the circuit breaker and an imbalance relay containing two detector units and a magnetic summator. The supply to the unit in 50 V dc and the trip circuits of each unit are interconnected to the others of the section, such that an operation of any unit will cause all four circuit breakers supplying the section to trip.

Application. Each detector unit produces an oscillating direct current, which passes through the main toroid windings and also through the primary winding of the unit's summator. This current will vary with the magnitude and direction of the main load current flowing through the track supply cables.

Under normal service conditions, the output of the two detectors will balance. Under unbalanced condition, the unbalance is reflected in the output of the summator, which causes auxiliary relays to operate to indicate the direction of the unbalance. To isolate the track section, the output of the unit having the unbalance is compared with the output of the unit on the adjacent parallel track. If an opposite polarity unbalance is present, the unit with the positive unbalance will initiate the trip circuit of its own circuit breaker and intertrip all other circuit breakers supplying that particular track section, thus effectively extinguishing any arcing that may be occurring due to the fault.

In order to resume the service, the supply to each parallel track is restored from one end only, one track from each of the two supply substations. Thus, even though the initial faults still remain, they become isolated.

Where large areas of traction current rails are connected together, unbalance current protection is less effective. Although it can still determine that two trains have complementary faults, these trains cannot be isolated easily. Also, UCP only operates when there are two trains with complementary faults.

Earth Fault Detector (17)

LTE has also reported using the traction earth fault detector in the areas where UCP equipment seems less effective.

Traction earth fault detector units, however, indicate immediately when a train develops a fault either positive or negative to frame. This information is transmitted to a central control center where, by programmed traction switching, the faulty train can be pin pointed and taken out of service remotely.

The nominal resistance between positive/negative traction rails to continuous running rail was found to be in the order of 2:1. Therefore, a 200-ohm resistance was connected between the positive and running rail and 100 ohms between the negative and running rail to maintain this balance. Voltage across the

100-ohm resistance is monitored, and if this falls below 50 V, a negative fault is indicated; or above 450 V, a positive fault.

This voltage is also continuously recorded at the central control center for use when an investigation into an earth fault is required.

Timed Overload Device (1)

This is a fixed time delay unit being used to detect a low level fault without using a rate-of-rise device. It operates if the low level fault current persists longer than a set time delay assuming the train starting peak current lasts for a short time of the value less than the breaker trip rating. The range of current settings for the device depends on the type of system and other protective devices incorporated, but the timed overload devices are usually arranged to have a range of 50 percent to 200 percent of the feeder breaker rated current.

Diode in the Negative Return Circuit

One U.S. system and one overseas system reported using a diode and a switch across the diode in the substation negative return circuit. The intent here is to provide instantaneous alarm and indication when the diode starts conducting because of the increased ground potential.

DEVICES BEING USED ON-BOARD ROLLING STOCK

In the responses received from both U.S. and overseas systems as well as from manufacturers, very little information was made available for the devices being used on-board cars. Some of the devices most predominantly reported are simple and do not require explanation.. They are:

- Fuses.
- Overcurrent relays in traction motor and in motor-alternator set motor.
- Line and ground differential current devices.
- High-speed circuit breaker mounted underneath the car or on the top.

A few transit systems overseas reported modifying the car control circuit for early detection of fault current; nevertheless, not enough information was provided to include in this section.

Columbia Components Inc. of New Jersey provided information in which the development of protective devices for ground fault and dynamic brake traction motor and heater fault detection systems were indicated. The detection device uses saturable reactors, miniature relays, and indicating lamps. The U.S. transit system which used this prototype device, along with the manufacturer itself, claims that the device performs satisfactorily.

In general, transit systems worldwide predominantly use high-speed circuit breakers (HSCB), differential devices, and overcurrent devices on cars, with the bystanding protection of a TP system, as discussed earlier in this appendix. The HSCB are reported provided by Alsthom, BBC, and Siemens. Only BBC provided technical data for the HSCB it offers.

DC High-Speed Circuit Breaker (*17*) (HSCB)

General

BBC offers HSCB to interrupt overloads and short circuits in traction vehicles at very high speed. The HSCB type UR-6 are recommended by the firm for light rail applications, while UR-12 can be used for all types of transit systems, commuter lines, and railroads. Types UR-6 and UR-12 are very similar in construction and application; however, UR-12 is selected for discussion here. The HSCB type UR-12 is a single-pole unit with electromagnetic blowout, electrical or pneumatic drive, direct and indirect (optional) tripping, and natural cooling. It can be mounted horizontally or vertically on the top, in, or under the car, has high resistance to vibration and mechanical shocks, and is enclosed in an insulating capsule. The HSCB conforms to IEC Recommendations Nos. 77 and 157.1.

Construction

Circuit breakers of type UR-12 are made up of the following main parts (note in the following that the numbers in parentheses refer to Figure F-18):

- *Main circuit*—comprising 2 copper bars (101, 102) and a moving contact (116).
- *Mechanism (210)*—comprising a trip and rod (208), a latch (211), and a pressure spring (212).
- *Closing device*—comprising a solenoid (300) (or a pneumatic drive) and a lever (305).
- *Tripping systems*—comprising a direct tripping device (400) and an indirect tripping coil (402).
- *Auxiliary switches (500)*—all of the above-mentioned parts are enclosed in an insulating chassis.
- *Arc chute (600)*—enclosed in a blowout chamber.

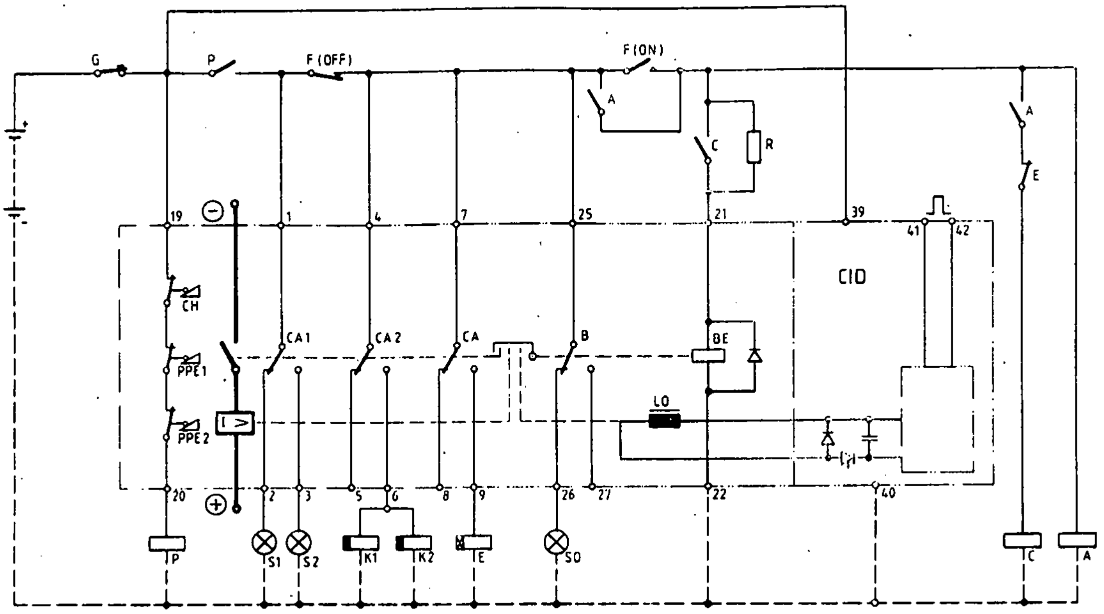
The contacts are made of Ag Cdo plates brazed on copper supports. The insulating chassis and the blowout chamber are made of polyester reinforced fiber-glass. The arc chute is made of refractory material. The circuit breaker is supplied with a multi-pin connector comprising a male socket and a female plug. The female plug is supplied with 1.5 mm^2 contacts of the crimped type. Figure F-14 shows the connection and block diagram of HSCB control schematic.

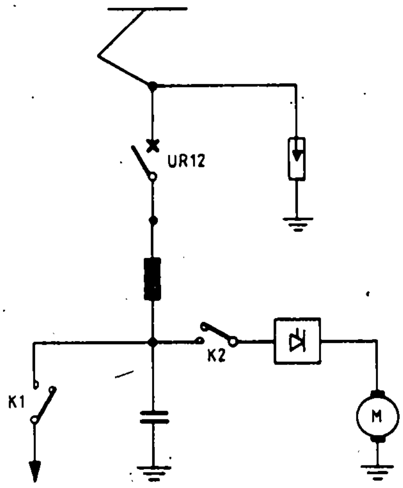
Application

Figure F-15 defines the technical characteristics.

The breaking capacity represents the current value which would be reached without circuit breaker operation. The current actually interrupted $\hat{I}_d$ depends on the time constant τ or on the $(di/dt)_o$ of the protected circuit. The characteristics are given in Figure F-16, for direct tripping and for indirect tripping, to show the relation between the short circuit current I_{cc}, the interrupted current $\hat{I}_d$, the time constant τ, and the initial rate of rise $(di/dt)_o$.

A fast indirect tripping, in addition to the direct tripping (which works on the trip-free principle, i.e., the trip always overrides the close of any part of closing stroke), in type UR-





Circuit-breaker UR 12

BE = closing and holding coil
CA 1 to 5 = auxiliary switches (switch over before main contact closing)
B = signalling contact of the closing device position
CH = safety-contact for arc chute
PPE 1 and 2 = safety contacts for spark arrester plates.
LO = impulse coil for indirect fast tripping (optionnal)
CID = impulse generator for indirect fast tripping (optionnal)

Components of the control circuits
(not supplied with the circuit-breaker)

G = control and protection CB
P = safety relay
F = ON-OFF pushbuttons
A = holding relay
C = auxiliary relay
E = slow-operating relay (0.5 to 1.5 s)
R = holding resistance
SO = signal lamp, circuit-breaker ready for closing
S1 = signal lamp, circuit-breaker open
S2 = signal lamp, circuit-breaker closed
K1 = slow releasing relay, H.V. auxiliary circuits
K2 = slow releasing relay, H.V. propulsion circuits

Figure F-14. Connection and block diagram of HSCB control schematic (18).

Definitions

$\hat{I}_{cc}$ = Transient short-circuit current = KI_{cc}

I_{cc} = Stationary short-circuit current = $\frac{Ud}{R}$

I_{ds} = Tripping current

$\left(\frac{di}{dt}\right)_0$ = Initial rate of rise $= \frac{U_d}{L} = \frac{I_{cc}R}{L} = \frac{I_{cc}}{\tau}$

$\hat{I}_d$ = Interrupted limit current

U_d = Recovery voltage

$\hat{U}_d$ = Max. arc voltage

$\langle\hat{U}_d\rangle$ = Average value of the arc-voltage

T_m = Contact opening time

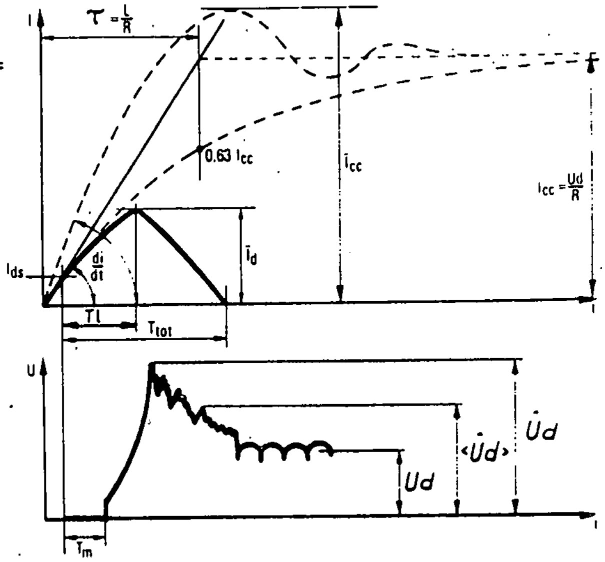
T_l = Current limiting time

T_{tot} = Total breaking time

τ = Time constant of the circuit $= \frac{L}{R} = \frac{Icc}{(di/dt)o}$

L = Circuit inductance

R = Circuit resistance



Rated current and overloads

The rated continuous current is 1200 A for an ambient temperature of 40°C.

The ciruit-breaker withstands the following max. currents of short duration:
- during 2h : 1300 A
- during 20min: 1850 A
- during 4min: 2400 A

Direct tripping current scale

The direct tripping current scales are:

- 600 to 1200 A or
- 1200 to 2400 A

Maximum continuous permissible voltage

Three arc chutes are available to cover the following range of voltage:

Arc chute Model 21 up to 1000 V
" " " 22 " " 2000 V
" " " 24 " " 4000 V

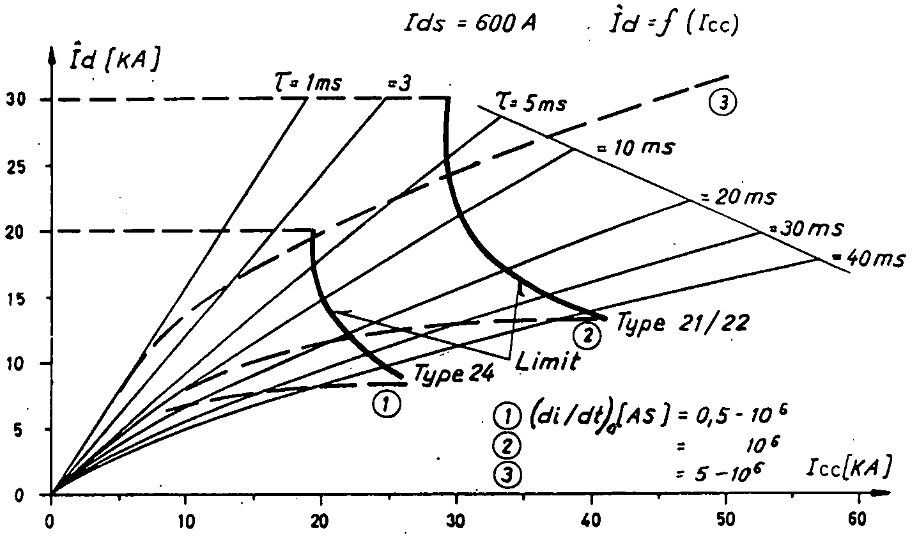
Arc voltages

When the contacts open, the arc voltages appearing at the circuit-breaker terminals have the following values:

UR 12...21: $\hat{U}d$ = 1600 V ; $\langle\hat{U}d\rangle$ = 1400 V
UR 12...22: $\hat{U}d$ = 3200 V ; $\langle\hat{U}d\rangle$ = 2800 V
UR 12...24: $\hat{U}d$ = 6000 V ; $\langle\hat{U}d\rangle$ = 5100 V

Figure F-15. Definition of technical characteristics of HSCB (18).

a. Direct tripping



b. Indirect tripping

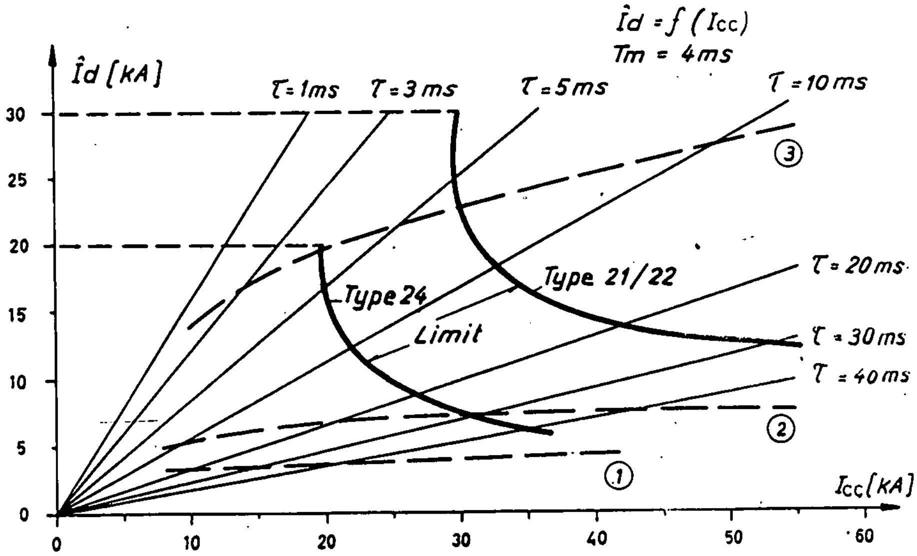


Figure F-16. I_{cc} *vs* $\hat{I}_d$ *characteristics of HSCB* (18).

12 circuit breakers can be supplied (as an option). With this tripping system, very much faster operating times over the conventional electromagnetic release are obtained. The indirect tripping system comprises an impulse coil acting directly on the trip latch. It also comprises an electronic control unit incorporating a capacitor storage tripping supply and an electronic switch. The impulse coil is located inside the insulating chassis, and the electronic control unit box is located on the insulating chassis.

Figures F-17(a), (b), and (c) show, for direct tripping, the relation between the contact opening time T_m, the current limiting time T_ℓ, the total breaking time T_{tot}, and the short circuit current I_{cc}, the time constant τ, the initial rate of rise $(di/dt)_o$ for a tripping current I_{ds} set at 600A.

For indirect tripping the contact opening time T_m does not depend on the characteristics of the network. For the lower permissible control voltage, T_m does not exceed 5 msec. The total breaking time T_{tot} is given by Figure F-17(d).

The detailed operation is described in the following, and is shown pictorially in Figure F-18.

- *Closing*—The moving contact (116) is operated by the closing device (300) through the lever (305). The moving contact is joint to the mechanism (210). During the first phase, only the opening spring connected to the mechanism works. During the second phase, the moving contact and the mechanism remain steady and the pressure spring (212), located inside the mechanism, works. The holding is done for the electrical holding, by the same solenoid used for operating the closing but with a reduced current; and for the magnetic holding, by a permanent magnet located inside the closing device.
- *Low-speed release*—Is accomplished by de-energizing the closing coil (for electrical holding) or by sending a reverse current impulse in the closing coil (for magnetic holding). The sequences as described for the closing are reversed.

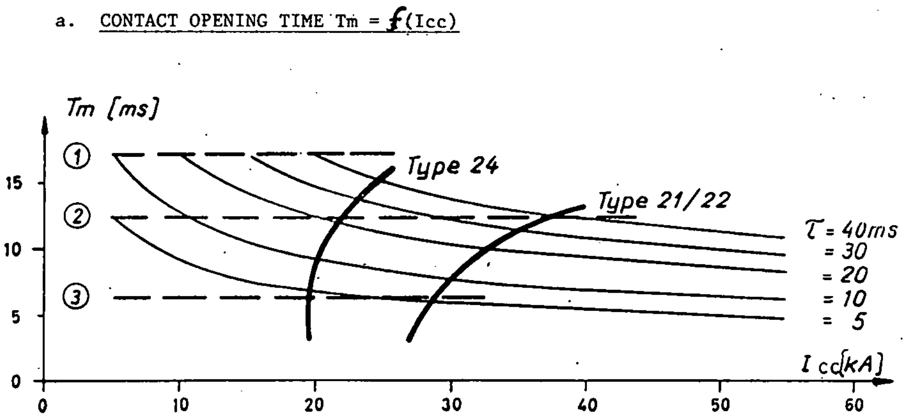


Figure F-17(a). I_{cc} vs T_m relationship for HSCB (18).

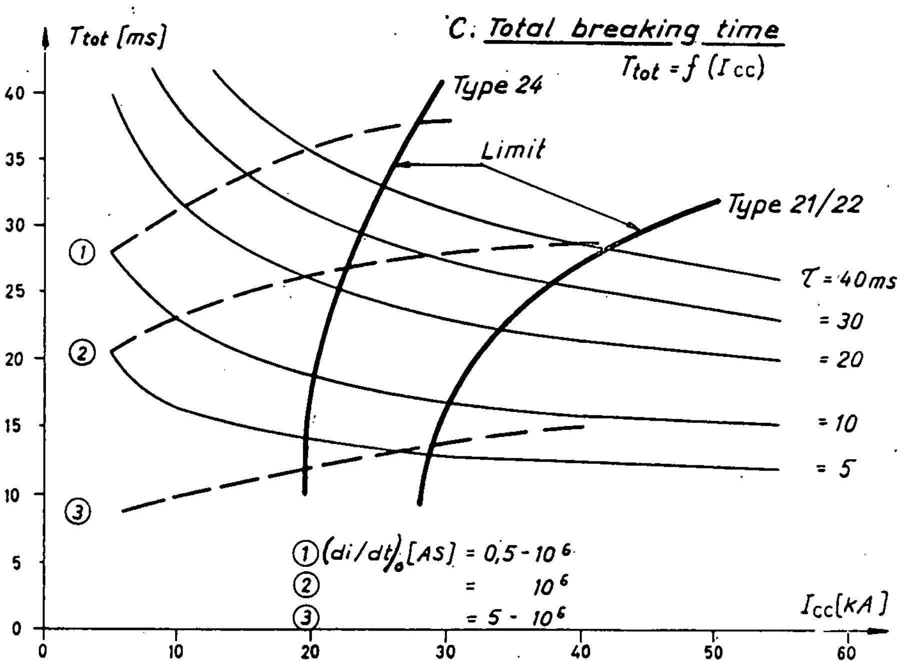


Figure F-17(c). I_{cc} vs T_{tot} relationship for HSCB (18).

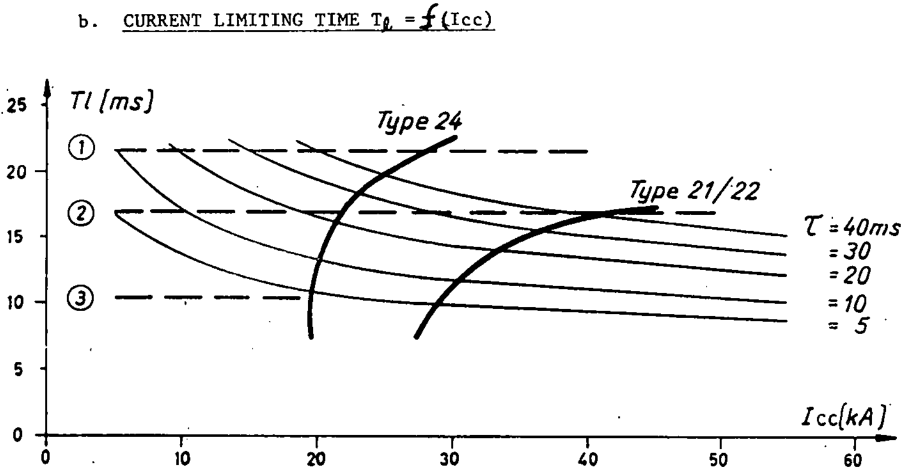


Figure F-17(b). I_{cc} vs T_ℓ relationship for HSCB (18).

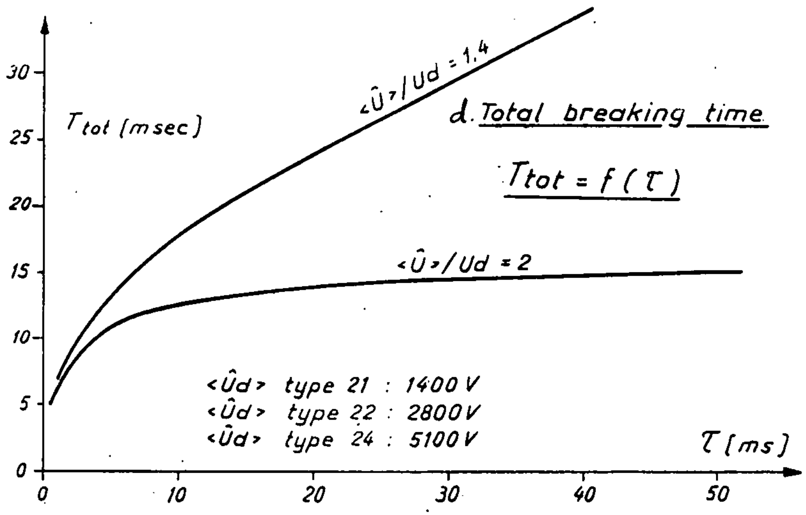
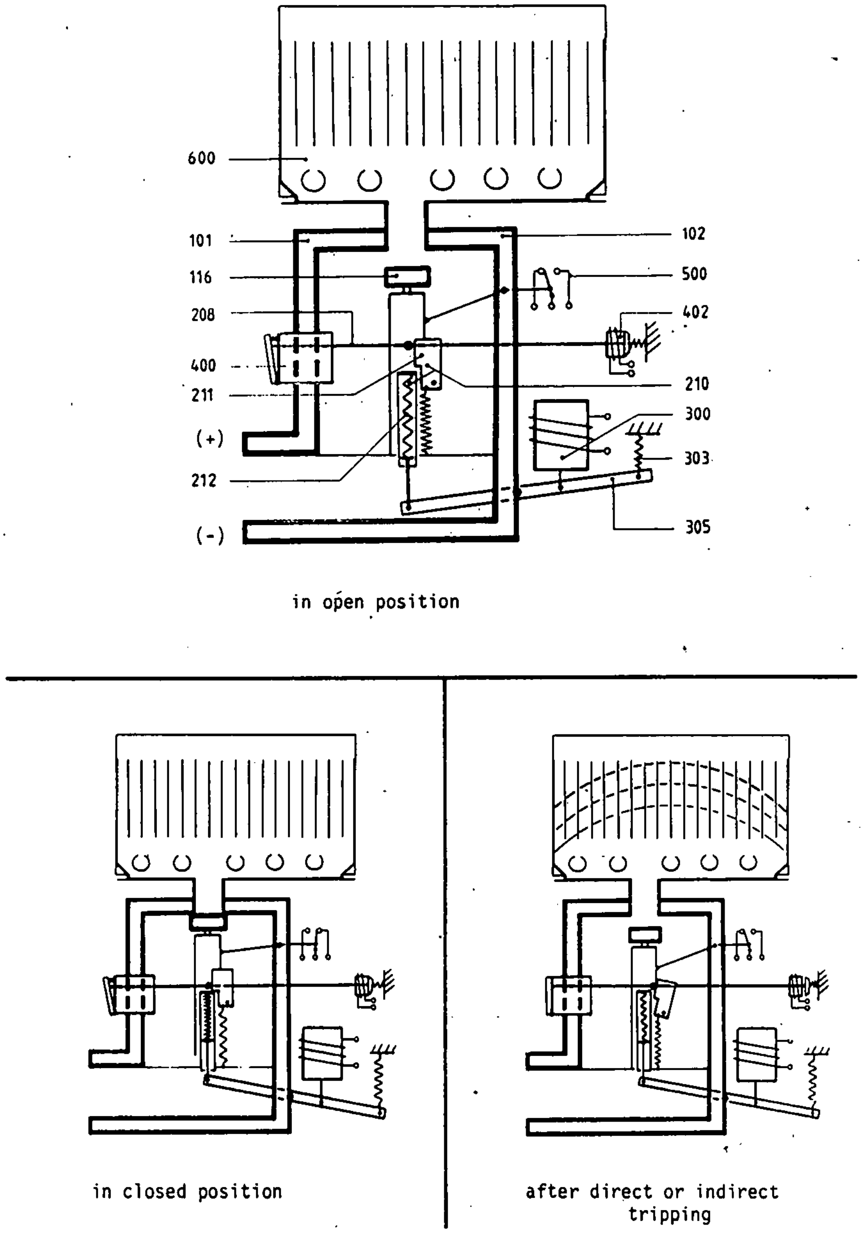


Figure F-17(d). τ vs T_{tot} relationship for HSCB (18).



in open position

in closed position

after direct or indirect tripping

Figure F-18. Operating mechanism of HSCB (18).

- *High-speed release*—The direct acting tripping system operates when the current in the copper bars has reached the threshold setting of the direct tripping device (400); this device acts on the trip rod (208) which releases the latch (211). The direct tripping system works on the trip-free principle, i.e., the trip always overrides the close at any part of closing stroke. In indirect acting tripping, an electronic system controls an electronic switch which connects a capacitor storage supply to the indirect tripping coil (402). This coil acts on the trip rod (208) which releases the latch (211).

During the break operation, the arc is moved up into the arc chute by the magnetic field generated by the current flowing in the main circuit. The arc chute is of the cold-cathode type, comprising a number of bare-metal plates arranged at right-angles to the length of the arc chute, with spacers between the plates to allow the arc to be split up into a number of series arcs.

APPENDIX G

ORGANIZATIONS CONTACTED

FOR TEST QUESTIONNAIRES

Transit Systems*

- Massachusetts Bay Transportation Authority (MBTA)
- Washington Metropolitan Area Transit Authority (WAMATA)
- Bay Area Rapid Transit Authority (BART)
- Port Authority of New York and New Jersey (PATH)
- Chicago Transit Authority (CTA)
- Commission de Transport de la Communanté urbaine de Montréal (CTCUM)

Manufacturers and Suppliers

- Ohio Brass Co. OH, USA
- AEG Telefunken, Federal Republic of Germany
- Perelli Construction & Co. Ltd. England, U.K.
- ASEA AB-Transport Div., Sweden
- Brown Boveri & Co. Ltd., Switzerland

Associations

- International Union of Railways, Paris, France
- Canadian Urban Transit Association Toronto, Canada
- Private Railways Association of German Federal Republic Federal Republic of Germany
- Japan Railway Engineers Association Tokyo, Japan
- Institute of Electrical Engineers London, England
- Institute of Electrical & Electronics Engineers - Power System Relaying Committee, U.S.A.

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*Both Questionnaires I & II were mailed

Other Industries**

- Iron and Steel Society Washington, DC
- Association of Iron and Steel Engineers Washington, DC
- American Iron and Steel Institute Washington, DC
- American Society of Mining Engineers Denver, Colorado
- National Coal Association Washington, DC
- Bituminous Coal Operations Assoc. Washington, DC
- American Mining Congress Washington, DC
- Bureau of Mines (USDIO) Washington, DC & Pittsburgh, Pennsylvania
- USDOL - Office of Mine Safety and Health Washington, DC
- USDOL - Research Center Tridelphia, West Virginia
- Boston Edison Co. Boston, Massachusetts
- New York Power Authority New York, New York

FOR FORMAL SURVEY

Transit Systems - Surveyed Through UITP

- *Linzer Elektrizitäts - Fernwärme and Verkehrsbetriebe AG (ESG) Linz, Austria
- *Wiener Stadtwerke Verkehrsbetriebe (WSV) Wien, Austria
- *Metropolitan Transit Authority (MTA) Melbourne, Australia
- State Rail Authority of New South Wales (NSW) Sydney, Australia
- *Société des Transports Intercommunaux de Bruxelles (STIB) Bruxelles, Belgien
- *Société Nationale des Chemins de Fer Vicinaux (SNCV) Bruxelles, Belgien
- Maatschappij voor het Interommunaal Vervoer te Gent (MIVG) Gentbrugge, Belgien
- *Maatschappij voor het Intercommunaal Vervoer te Antwerpen (MIVA) Antwerpen, Belgien
- Companhia do Metropolitano de Rio de Janeiro (Metrô de Rio) Rio de Janeiro, Brazil

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**Telephone Test Survey Only

*Selected for Mailing Questinnaire II

*● Companhia do Metropolitano de São Paulo (Metro de S. Paulo) São Paulo, Brazil

*● The City of Calgary Transit System (CDN) Calgary, Alberta Canada

● Commission de Transport de la Communauté Urbaine de Montréal (CTCUM) Montréal, Québec, Canada

● Toronto Transit Commission (TTC) Toronto, Ontario, Canada

● Verkehrsbetriebe Zürich (VBZ) Zürich, Switzerland

● Dopravní Podniky Hlavního Města Prahy (DPMP), Praha, Czechoslovakia

*● Berliner Verkehrs - Betriebe Eigenbetrieb von Berlin (BVG) Berlin, Federal Republic of Germany

● Rheinische Bahngesellschaft AG (RhB) Düsseldorf, Federal Republic of Germany

*● Hamburger Hochbahn Aktiengesellschaft (HHA) Hamburg, Federal Republic of Germany

*● Üstra Hannoversche Verkehrsbetriebe AG (ÜSTRA) Hannover, Federal Republic of Germany

*● Stadtwerke München Verkehrsbetriebe (MVG) München, Federal Republic of Germany

● Stuttgarter Strassenbahnen Aktiengensellschaft (SSB) Stuttgart, Federal Republic of Germany

*● F. C. Metropolitá de Barcelona S.A., S.P.M. (FCMB) Barcelona, Spain

*● Compañia Metropolitano de Madrid (CMM) Madrid, Spain

*● Cie du Metro de Lille (COMELI) Lille, France

*● Société Lyonnaise de Transports en Commun (TCL) Lyon, France

● Régie Autonome des Transports de la Ville de Marseille (RATVM) Marseille, France

● Régie Autonome des Transports Parisiens (RATP) Paris, France

*● Strathclyde Passenger Transport Executive (SPTE) Glasgow, Great Britain

● Merseyside Passenger Transport Executive (MPTE) Liverpool, Great Britain

*● London Transport Executive (LTE) London, England

● Greater Manchester Passenger Transport Executive (GMT) Manchester, Great Britain

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*Selected for Mailing Questionnaire II

*● Tyne and Wear Passenger Transport Executive (TWPTE) Newcastle Upon Tyne, Great Britain

● Athens-Piraeous Electric Railways Co. Ltd. (A-PER) Athens, Greece

*● Budapesti Közlekedési Vállalat (BKV) Budapest, Hungary

*● Mass Transit Railway Corporation (MTRC) Hong Kong

● Azienda Transporti Municipali (ATM) Milano, Italy

● Azienda Consortile Transporti Laziali (ACOTRAL) Roma, Italy

● Consorzio Transporti Torinesi (TT) Torino, Italy

● Transportation Bureau of Tokyo Metropolitan Government (TBTMG) Tokyo, Japan

● Japanese National Railways (JNR) Tokyo, Japan

● Teito Rapid Transit Authority (TRTA) Tokyo, Japan

*● Sistema de Transporte Colectivo (STC) Mexico

*● Aktieselskabet Oslo Sporveier (OS) Oslo, Norway

● Gemeentevervoerbedrijf Amsterdam (GVB) Amsterdam, Netherlands

● N.V. Gemengd Bedrijf Haagsche Tramweg Maatschappij (HTM) Gravenhage, Netherlands

● Rotterdamse Elektrische Tram (RET) Rotterdam, Netherlands

*● Metropolitano de Lisboa, E.P. (CML) Lisboa, Portugal

● Companhia Carris de Ferro de Lisboa (CARRIS) Lisboa, Portugal

● Miejskie Zaklady Komunikacyjne (MZK) Warszawa, Poland

● Subterraneos de Buenos Aires (SBA) Buenos Aires, Argentina

*● Ministerio de Obras Publicas, Dirección General de Metro (MCMS) Santiago de Chile, Chile

*● Göteborgs Spårvägar (GS) Göteborg, Sweden

● Svenska Lokaltrafikforeningen (SLTF) Stockholm, Sweden

*● Helsingin Kaupungin Liikennelaitos (HKL) Helsinki, Finnland

*● Istanbul Belediyesi Istanbul Elektrik Tramway ve Tünel Isletmeleri (IETT) Istanbul, Turkey

*● République Tunisienne, Ministére des Transports et des Communications, Direction des Transports (CMLT) Tunis, Tunisia

*● Moskovsky Metropolitan Imeni Lenina (MMIL) Moscow, USSR

● Metropolitan Atlanta Rapid Transit Authority (MARTA) Atlanta, Georgia

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*Selected for Mailing Questionnaire II

- *Chicago Transit Authority (CTA) Chicago, Illinois
- Metropolitan Transit Authority of Houston (MTA) Houston, Texas
- *New York City Transit Authority (NYCTA) New York, New York
- *Port Authority of New York and New Jersey (PATH) New York, New York
- *Southeastern Pennsylvania Transportation Authority (SEPTA) Philadelphia, Pennsylvania
- *Municipal Railways (MUNI) San Francisco, California
- *C. A. Metro de Caracas (MC), Caracas, Venezuela
- Gradski Saobrácaj Beograd (GSB) Beograd, Yugoslavia

TRANSIT SYSTEMS - SURVEYED DIRECTLY

- *The City of Edmonton Edmonton, Canada
- VE Kombinat Berliner Verkehrs-Betriebe (VEB) East Berlin, German Democratic Republic
- Stadtwerke Munchen Verkehrsbetriebe (SMV) Munich, Federal Republic of Germany
- Wuppertaler Stadtwerke AG (WS) Wuppertal, Federal Republic of Germany
- Municipal Transportation Bureau (MTB) Fukuoka, Japan
- Kyoto Transportation Bureau (KTB) Kyoto City, Japan
- Osaka Municipal Transportation Bureau (OMTB) Osaka, Japan
- Seoul Metropolitan Rapid Transit Bureau (MRT) Seoul, Republic of Korea
- New Zealand Railway Corporation Wellington, New Zealand
- Interprindere Metroul Bucuresti Bucharest, Romania
- Baku Metropolitan Baku, USSR
- Tashkent Metropolitan Tashkent, USSR
- *Massachusetts Bay Transportation Authority (MBTA) Boston, MA
- *Greater Cleveland Regional Transit Authority (RTA) Cleveland, Ohio
- *Long Island Railroad (LIRR) Jamaica, New York
- Port Authority Transit Corporation (PATCO) Camden, New Jersey
- Port Authority of Allegheny County (PAT) Pittsburgh, Pennsylvania
- *San Diego Metropolitan Transit Development Board (MTDB) San Diego, California
- *Bay Area Rapid Transit District (BART), Oakland, California

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*Selected for Mailing Questionnaire II

EQUIPMENT MANUFACTURERS/SUPPLIERS - SURVEYED DIRECTLY

- Brown Boveri TRM Industries Inc. Lachine, Québec, Canada
- AEG - Telefunken Anagentechnik AG W. Berlin, Federal Republic of Germany
- Ercole Marelli Elettro Meccanica, Milan, Italy
- BBC - Sécheron SA Geneva, Switzerland
- Stone (McColl) Pty. Ltd., Victoria, Australia
- Carbone Lorraine Corporation, Dorion, Québec, Canada
- Ansaldo Transporti SpA, Naples, Italy
- Toshiba Corporation, Tokyo, Japan
- Jeumont - Schneider, La Plaine St. Denis, France
- Sasib SpA, Bologna, Italy
- General Railway Signal Co., Rochester, New York
- Ateleirs de Constructions Electriqués de Charléroi, Charléroi, Belgium
- Mitsubishi Electric Corporation, Tokyo, Japan
- AVM Systems Inc., Fort Worth, Texas
- Union Switch and Signal, Swissvale, Pennsylvania
- Nippon Sharyo Seizo Kaisho Ltd., Nagoya, Japan
- ASEA AB, Västerås, Sweden
- GEC Traction Limited, Manchester, England
- The Budd Company, Troy, Michigan
- Kawasaki Heavy Industries Ltd., Minato-Ku, Japan
- Daewood Heavy Industries Ltd., Incheon, Korea
- Brown Boveri & Cie, Baden, Switzerland
- Metro - Cammell Ltd., Birmingham, England
- Alsthom - Atlantique, Paris, France
- Duewag AG, Düsseldorf, Federal Republic of Germany
- Ganz Má Vag Locomotive and Railway Carriage Mfrs., Budapest, Hungary
- Breda Costruziono Ferroviarie SpA, Pistoria, Italy
- Société MTE, Puteaux, France
- Maschinenfabrik Augsburg-Nürnberg (MAN) Aktiengesellschaft, Nümerberg, Federal Republic of Germany
- Indian Railway Integral Coach Factory, Madras, India

- Hitachi, Ltd., Tokyo, Japan
- Walkers Ltd., Queensland, Australia
- Mafersa, São Paulo, Brazil
- Scandia - Randers A/S, Randers, Denmark
- Simmering-Graz-Pauker AG, Vienna, Austria
- CK̂D Praha - Tarta Works, Prague, Czechoslovakia
- Valmet Oy, Helsinki, Finland
- General Electric Company, Erie, Pennsylvania
- Faiveley SA, Saint-Ouen Cedex, France
- Fuji Electric Co. Ltd., Tokyo, Japan
- SAE (India) Limited, New Delhi, India
- Ohio Brass Company, Mansfield, Ohio
- Westinghouse Electric Corporation, Pittsburgh, Pennsylvania
- Hubbell-Ensign Electric Division, Huntington, West Virginia
- Columbia Components, Ridgefield, New Jersey
- CERME Eléctroniqué, Chavillé, France
- Merlin Gerin SA, Cédex, France
- ASEA Inc., Yonkers, New York
- Siemens Electric Co., Point Claire, Canada
- Siemens-Allis, Atlanta, Georgia
- Breda Construzioni Ferrouiarie, New York, New York
- UTDC (USA) Inc., Detroit, Michigan
- The Budd Company, Philadelphia, Pennsylvania
- Nissho Iwai American Corporation, New York, New York
- Sumitomo Corporation of America, New York, New York
- BN Construciones Ferrouiaries Et Mettaliques S.A., Bruxelles, Belgium
- Franco Rail, New York, New York
- Mitsubishi International Corporation, New York, New York
- Bombardier Corporation, Brooklyn, New York
- Marubeni America Corporation, New York, New York
- Soferval Inc., Oakland, California
- Safety Electrical Equipment Corp., Wellingford, Connecticut
- GEC/English Electric Co., Port Chester, New York

PROFESSIONAL ASSOCIATIONS - SURVEYED DIRECTLY

- Association Internationale des Constructeurs de Materiel Roulant (AICMR), France
- Union of African Railways (UAR), Zaire
- Australian Railway Research & Development Organization, Melbourne, Australia
- Association Internationale de Congres des Chemis de Fer, Belgium
- Latin American Railway Associatin, Argentina
- Association des Fabricants Europeens d'Equipements Ferroviaires, France
- Bundesverband Deutscher Eisenbahnen (BDE), Federal Republic of Germany
- Japan Railway Engineers Association, Tokyo, Japan
- Institution of Electrical Engineers, England
- Canadian Urban Transit Association, Canada
- Japan Railway Electrification Assoc. Inc., Tokyo
- Chartered Institute of Transport, England
- American Public Transit Assoc. (APTA), Washington, DC
- U.S. Department of Health, Washington, DC
- Power Conversion Products Council, Chicago, Illinois
- National Association of Relay Manufacturers, Indiana
- National Electrical Manufacturers Association, Washington, DC
- National Transportation Safety Board, Washington, DC
- Texas A&M University, Texas
- Institute of Electrical & Electronics Engineers Protective Relaying Committee, Florida
- Edison Electric Institute, Washington, DC
- American Association of Railroad, Washington, DC
- American Railway Engineers Association, Washington, DC

OTHER INDUSTRIES - SURVEYED DIRECTLY

Utilities

- Arizona Public Service Company, Arizona
- Baltimore Gas & Electric Co., Maryland
- Boston Edison Co., Massachusetts
- The Dayton Power and Light Company, Ohio
- American Electric Power Co., Ohio
- Arkansas Power & Light Co., Arkansas
- Bonneville Power Administration, Oregon
- Cambridge Electric Light Co., Massachusetts
- Florida Power & Light Co., Florida
- GPU Service Corporatin, New Jersey
- Juneau Utility Commission, Wisconsin
- Nebraska Public Power District, Nebraska
- Delaware Power & Light Co., Delaware
- Georgia Power Co., Georgia
- Gulf States Utilities Co., Texas
- Los Angeles Department of Water & Power, California
- Northeast Utilities Service Company, Connecticut
- Pacific Gas and Electric Co., California
- New York Power Authority, New York
- Tennessee Valley Authority, Tennessee
- New England Power Service Co., Massachusetts
- Ohio Edison Co., Ohio
- Pennsylvania Power & Light Co., Pennsylvania
- San Diego Gas & Electric Co., California
- Virginia Electric and Power Co., Virginia
- Wisconsin Power & Light Co., Wisconsin
- Texas Utilities Company, Texas
- Washington - St. Tammany Elec. Coop. Inc., Louisiana

Mining Concerns

- CERCHAR Industrie En - Halatte, France
- American Institute of Mechanical Engineers - Iron and Steel Society, Washington, DC
- American Society of Mining Engineers, Denver, Colorado
- American Iron and Steel Institute, Washington, DC
- National Coal Association, Washington, DC
- Bituminous Coal Operations Associations, Washington, DC
- American Mining Congress, Washington, DC
- Bureau of Mines, U.S. Department of Interior, Washington, DC
- Bureau of Mines, Pittsburgh, Pennsylvania
- Office of Mine Safety and Health - U.S. Department of Labor, Washington, DC
- Research Center, U.S. Department of Labor, Tridelphia, West Virginia
- Henderson Mine, Colorado
- Climax Molybdenum Co., Colorado
- Vapor Corporation, Chicago, IL

APPENDIX H

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The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine.

The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the federal government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

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National Research Council
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