quires a recognition of both utility and railroad problems and a willingness on the part of utilities, railroads, and government to consider all the issues involved. These issues include changes in operating techniques and new concepts with respect to rate structures and contractual arrangements.

REFERENCE


Canadian Railway Electrification Study: Phase 1

E. R. Cornell, Canadian Institute of Guided Ground Transport, Kingston, Ontario

The Canadian Railway Electrification Study was commissioned by the Railway Advisory Committee and funded through the Canada Department of Transport's Transportation Development Agency to (a) bring into sharper focus the time frame in which it might be expected that electrification of significant portions of Canadian railways is likely to occur and (b) develop and describe a program of investigation, research, and development designed to permit a smooth transition to reliable operation at that time.

It was not intended that the study resolve the question of whether electrification will, or should, take place; the terms of reference required the presumption that it will occur at some future time. However, the study has provided considerable background information that would be necessary to make a decision concerning rail electrification, and it aids in identifying additional studies that would be necessary to such a decision. The study examined a number of factors, including:

1. The future supply and costs of hydrocarbon fuels for railway operations in Canada;
2. A comparison of the technical features of diesel-electric and electric locomotives, including a comparison of capital and operating costs;
3. The future supply and costs of electric energy for railway traction;
4. The technical and cost features of high-voltage overhead catenary;
5. The effects of inductive interference on signaling and communication systems, including a discussion of the nature of the interference and design factors that affect the degree of interference generated;
6. System operating considerations;
7. The requirement for an operational prototype for the Canadian situation;
8. An economic evaluation for a specific, but typical, 650-km (400-mile) segment to determine the importance of numerous factors on both the financial return and the optimum timing for electrification;
9. An examination of rail traffic volume, with projections for the future for main-line track of both the Canadian National Railways and the Canadian Pacific Ltd. and the development of a possible implementation sequence for electrification of roughly 15 300 track km (9500 track miles) over a 30-year period;
10. Identification of some implications of rail electrification;
11. Consideration of the scale and nature of the capital financing required for electrification and its impact on the Canadian economy; and
12. Identification of the additional study necessary to resolve both technical and financial questions and the steps and time required to complete a prototype operating system.

ENERGY SUPPLY AND COST

If the future supply of diesel fuel to the railways could not be guaranteed, then the requirement for electrification of the rail network would become essential. This presumes that the railways continue to be an essential part of Canada's transportation system, that alternative railway fuels (such as hydrogen or coal-derived products) are not available, and that an adequate supply of electric energy is available.

After reviewing statements concerning petroleum supplies in Canada and allocation policies of the federal government, we concluded that Canadian railways will not be crippled by a lack of diesel fuel within the next 50 years. However, on the basis of limited world petroleum supplies, and the projections of crude oil prices, as shown in Figure 1, we must conclude that the relative price of petroleum-based fuels will rise faster than the general inflation rate would suggest. The projected world oil price suggests a price escalation rate 4 percent greater than the general inflation rate. This would lead to the projected diesel fuel costs shown below in terms of 1975 Canadian dollars (1 L = 0.26 gal).

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost ($/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0.163 to 0.205</td>
</tr>
<tr>
<td>1985</td>
<td>0.198 to 0.249</td>
</tr>
<tr>
<td>1990</td>
<td>0.242 to 0.304</td>
</tr>
</tbody>
</table>

In Canada, electricity is provided by provincially owned or regulated supply authorities. Each supply authority establishes its own price structure. Naturally, the demand load factor (the average demand divided by the peak demand during, for example, a 30-min period) will significantly affect electric costs. Hence, to provide a reasonable picture of the comparative costs shown in Table 1, we assumed a 650-km segment of track carrying 18 gross Tg/year (20 million gross tons/year) with substations at 65-km (40-mile) intervals, an energy consumption of 11.7 kW/gross Ggkm (17.1 kW/1000 gross ton-miles), and a power factor of 85 percent. As traffic levels increase, the load factor increases, thereby reducing the unit energy cost.

Rather than using individual substation metering, the possibility of system metering has been considered. This would involve connecting individual substations to a railway-owned distribution line from a single supply authority. Significant improvement in the load factor is possible, accompanied by a consequent reduction in the unit energy cost, as shown in Table 1.

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Rather than using individual substation metering, the possibility of system metering has been considered. This would involve connecting individual substations to a railway-owned distribution line from a single supply authority. Significant improvement in the load factor is possible, accompanied by a consequent reduction in the unit energy cost, as shown in Table 1.
Projections of the electric authority's generation capacity and the electrified railway's electric demand reveal that the railway load will be a relatively small portion of the total generation capacity. The annual growth of electric demand averages 6 to 7 percent for all of the supply authorities considered. As the table below illustrates, the railway demand might be considered significant only for Calgary Power, since the rail electrification would be spread over several years, there being a roughly 5-year construction period before the first impact of the demand.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Average Demand in 2000 (MW)</th>
<th>Percentage of Generating Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro Quebec</td>
<td>84.0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Ontario Hydro</td>
<td>273.0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Manitoba Hydro Electric Board</td>
<td>95.0</td>
<td>2</td>
</tr>
<tr>
<td>Saskatchewan Power Corporation</td>
<td>151.0</td>
<td>6</td>
</tr>
<tr>
<td>Calgary Power Ltd.</td>
<td>479.1</td>
<td>14</td>
</tr>
<tr>
<td>British Columbia Hydro and</td>
<td>504.8</td>
<td>8</td>
</tr>
<tr>
<td>Power Authority</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calgary Power and Alberta Power both supply electric energy to the province of Alberta through an interconnected system. Although in Alberta the candidate rail lines for electrification lie solely within the distribution area of Calgary Power, the interconnection of supply authorities would reduce the importance of the railway load on the Calgary Power system.

Projections of the price increases for electric energy reveal that the strong base provided by hydraulic and coal-based power generation and the continued development of efficient nuclear and coal-fueled power generation will result in a price-escalation rate that is lower than that for petroleum-based fuels. The need to conserve petroleum fuels, which are used for domestic and commercial heating, demands that the price escalation of electric energy be slightly less than that of petroleum fuels.

**LOCOMOTIVES**

We examined the design and performance aspects of the electric locomotive in detail, considering the similarities and differences between the electric and diesel-electric locomotive. Significant improvements in the North American diesel-electric locomotive are possible, and current developments will provide units that more closely match the performance of the modern electric locomotive. The performance of modern European electric locomotives is outstanding. However, the lighter axle load, lesser maintenance requirements, and other features of the European electric locomotive would make it unsatisfactory for Canadian service. We concluded that current electric locomotives built in North America could be used in Canadian service but that all available units are a long way from the optimum. However, it is clear that a unit designed specifically for the Canadian application could be built today.

Improved train performance is commonly claimed for electrically powered trains on the basis that they provide greater power per unit of train mass. Figure 2 illustrates the importance of adhesion to the tractive effort and the use of power for various axle-power ratings. Curve a, with an adhesion of 40 percent, roughly represents the maximum adhesion available with good track conditions and suitable locomotive design. Curve b (28 percent) represents a more realistic scheduled speed for a well-designed electric locomotive. There is an indication that adhesion decreases with increasing vehicle speed.

**Table 1. Unit energy costs for various load factors under individual substation metering and system metering.**

<table>
<thead>
<tr>
<th>Load Factor ($)</th>
<th>Ontario Hydro &amp; Hydro Quebec</th>
<th>Manitoba Hydro Electric Board</th>
<th>Saskatchewan Power Corporation</th>
<th>Calgary Power Ltd.</th>
<th>British Columbia Hydro and Power Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substation metering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0.65</td>
<td>0.69</td>
<td>0.60</td>
<td>0.64</td>
<td>0.84</td>
</tr>
<tr>
<td>20</td>
<td>0.79</td>
<td>0.82</td>
<td>0.70</td>
<td>0.68</td>
<td>0.99</td>
</tr>
<tr>
<td>16.7</td>
<td>0.92</td>
<td>0.94</td>
<td>0.80</td>
<td>0.73</td>
<td>1.14</td>
</tr>
<tr>
<td>14.3</td>
<td>1.04</td>
<td>1.07</td>
<td>0.90</td>
<td>0.77</td>
<td>1.29</td>
</tr>
<tr>
<td>12.5</td>
<td>1.17</td>
<td>1.19</td>
<td>1.00</td>
<td>0.82</td>
<td>1.43</td>
</tr>
<tr>
<td>11.1</td>
<td>1.31</td>
<td>1.32</td>
<td>1.10</td>
<td>0.86</td>
<td>1.58</td>
</tr>
<tr>
<td>10</td>
<td>1.45</td>
<td>1.44</td>
<td>1.20</td>
<td>0.91</td>
<td>1.73</td>
</tr>
<tr>
<td>System metering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.36</td>
<td>0.44</td>
<td>0.40</td>
<td>0.35</td>
<td>0.46</td>
</tr>
<tr>
<td>33.3</td>
<td>0.47</td>
<td>0.57</td>
<td>0.50</td>
<td>0.43</td>
<td>0.61</td>
</tr>
<tr>
<td>25</td>
<td>0.59</td>
<td>0.69</td>
<td>0.60</td>
<td>0.47</td>
<td>0.76</td>
</tr>
<tr>
<td>20</td>
<td>0.70</td>
<td>0.82</td>
<td>0.70</td>
<td>0.52</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Note: All values except load factors are expressed in cents/ megajoule (1 MJ = 0.27 kW.h). *Price may be slightly lower depending on the high-voltage feed level.*
This is a function of track characteristics and locomotive suspension design. Curve c attempts to illustrate this effect of speed.

Note on curve c that a 635-kW axle can produce full power at speeds exceeding 96 km/h (60 mph). However, a 1500-kW axle cannot produce full power until the vehicle’s speed exceeds 96 km/h (60 mph). Diesel-electric locomotives can also provide this improved performance, if that is an objective of train scheduling. Improved wheel-slip controls can raise the adhesion levels of diesel-electric locomotives to values that are only marginally lower than the adhesion levels achieved by the finest of electric locomotives. However, the diesel locomotive will continue to be restricted in power per axle to a level that may be below the optimum for most Canadian operations. The electric locomotive, on the other hand, will not be power restricted.

After reviewing the design aspects of the catenary system, including the consideration of materials, we recommended the use of the British Insulated Callender’s Construction Company Ltd. catenary, illustrated in Figure 3. The proposal includes a copper contact wire with an aluminum cable steel-reinforced (ACSR) messenger wire, and an ACSR ground return wire on the mast. The operating voltage would be 50 kV, with a 25-kV operation in restricted areas, such as tunnels. The power capacity of the standard catenary system would be up to 45 MW, with a substation supplying up to 90 MW in a center-feed connection. Mast material would be selected on the basis of price and local conditions. A mast setback of 3 m (10 ft) from the center line of the track, with an increase to 3.7 m (12 ft) on severe curves and in areas of heavy snowfall, was recommended.

Kendall’s paper in this report discusses signaling and communications. He provided much of the background information on this topic for our report. We examined sources of interference, results of interference, and their effects on equipment selection.

SYSTEM OPERATION

Electrification does not imply that diesel-electric locomotives will disappear. Local operations and branchline operations will be diesel powered. The conversion to electrified main-line operation would occur at a pace that would preclude the necessity of scrapping or selling diesel units.

Because of the relation between power and adhesion requirements for electric locomotives on most mainline tracks, the train power would exceed 820 W/Mg (1 hp/ton), and in most cases it would correspond to the level currently used on express trains. Simulations reveal that train schedules for a variety of typical trains would be almost identical. Electrically powered trains would operate with the same track speed limits and the same downgrade restrictions. On climbing grades, the greater power would reduce the schedule time required. The more uniform operation would permit some increase in track capacity.

The power demand of a typical train over a typical terrain, using the European control strategy, is shown in Figure 4. The variation in electric demand will cause problems for the supply authority. The variation of single-phase load on the utility’s three-phase system can create a phase imbalance. The severity of the problem depends on connection techniques, significance of the load, and the control strategy.

The electric locomotive can draw full power only after it attains a relatively high speed. The power to an individual locomotive can be limited by a central dispatcher using carrier signals. This would allow a cen-

ECONOMIC EVALUATION

The cost implications of rail electrification require a relatively sophisticated economic analysis to identify the effects of time, traffic growth, capital and operating costs, and so on. As a preliminary step toward economic evaluation, it was necessary to develop traffic projections for each segment of main-line track. The relatively long span of time involved (approximately 30 years) required the identification and evaluation of long-term factors. Population trends, resource development, and historical rail traffic records were considered in developing the projections. Figure 5 illustrates a typical

![Figure 2. Locomotive adhesion for various axle-power ratings.](image)

![Figure 3. Sagged simple catenary with steel column masts.](image)
traffic projection for a specific track segment. Note that the study projection is conservative, compared with the projection used by the railway for planning purposes. This was true of all study projections used.

Further detailed consideration of a 650-km track segment included simulations of train performance, actual train patterns over a 1-year period, derailments and other traffic restrictions, and a survey of modifications to physical structures that electrification would require. From this detailed information, the cost figures shown below were generated. As has been discussed in detail in the full report, the costs are derived from long-term intercept values; note that the fuel and energy costs are not expressed strictly as 1975 prices. The annual operating costs were as follows.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings</td>
<td></td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>7 943</td>
</tr>
<tr>
<td>Diesel maintenance</td>
<td>4 008</td>
</tr>
<tr>
<td>Track maintenance</td>
<td>336</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>12 287</strong></td>
</tr>
<tr>
<td>Costs</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>5 013</td>
</tr>
<tr>
<td>Electrical maint.</td>
<td>908</td>
</tr>
<tr>
<td>Catenary maint.</td>
<td>1 000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>6 921</strong></td>
</tr>
<tr>
<td><strong>Total annual cost savings</strong></td>
<td>5 366</td>
</tr>
</tbody>
</table>

The initial capital costs were as follows.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
</tr>
<tr>
<td>Electric locomotives</td>
<td>13 932</td>
</tr>
<tr>
<td>Fixed plant (catenary, signaling maintenance facilities, and so on)</td>
<td>75 869</td>
</tr>
<tr>
<td>Planning</td>
<td>5 000</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
</tr>
<tr>
<td>Diesel locomotives</td>
<td>15 120</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>94 801</strong></td>
</tr>
<tr>
<td><strong>Total initial capital costs</strong></td>
<td><strong>79 681</strong></td>
</tr>
</tbody>
</table>

The cost of a locomotive fleet for a different traffic mix is based on a detailed analysis of locomotive cost estimates provided by General Motors. It is interesting to note that the capital cost of the locomotive fleet is essentially independent of the locomotive type, as illustrated below.

<table>
<thead>
<tr>
<th>Type of Locomotive</th>
<th>Number of Axles</th>
<th>Number of Units</th>
<th>Unit Price ($000)</th>
<th>Total Cost ($000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel units</td>
<td>6</td>
<td>40</td>
<td>1 160</td>
<td>22 400</td>
</tr>
<tr>
<td>Low-power electric</td>
<td>8</td>
<td>16</td>
<td>1 187</td>
<td>18 872</td>
</tr>
<tr>
<td>High-power electric</td>
<td>8</td>
<td>15</td>
<td>1 447</td>
<td>21 705</td>
</tr>
</tbody>
</table>

This is specific to the particular terrain characteristics, which include controlling grades of more than 1 percent, and a higher concentration of eastward traffic load. On most other segments, the capital cost of an electric fleet would tend to be lower than that of a diesel-electric fleet because the high-powered locomotives would be more effectively utilized.

Financial aspects were examined in a general way only, since the pertinent parameters for any given railway link depend on regional and local conditions. At the scale of investment that electrification implies, commercial viability must be judged on the specific terms of the corporate institution considering the investment.

**Methodology**

The research involved development of a methodology rather than a determination of the commercial viability of electrification. Within this methodology, the direction and relative magnitude of the impact of variations in selected cost and financial parameters were examined. The economic valuation procedure explores the basic premise that, under conditions of increasing real prices of petroleum in relation to other energy sources and of increasing traffic densities, eventual electrification of a substantial portion of the Canadian railway system would seem inevitable. The optimal timing for such a conversion will be dictated by projected changes in current operations and the values of financial parameters.
growth. The model calculates an incremental present value. The estimation of the impact of cost escalation on electrification is complex. Since they are determined by economic forces far removed from the corporate management, escalation rates are linked both to each other and to most of the other parameters of the model. Analysis was restricted to general parameter categories. In general, since the benefit from electrification is in savings in operating costs, increasing levels of cost escalation tend to increase the overall benefit. In addition, if there are higher escalation rates, operating cost savings of substantial magnitude are generated sooner, thus advancing the optimal timing for electrification. Similar effects are produced by a greater differential between the general cost-escalation rate and that applicable to operating cost components, e.g., diesel fuel.

Cost Escalation

The estimation of the impact of cost escalation on electrification is complex. Since they are determined by economic forces far removed from the corporate management, escalation rates are linked both to each other and to most of the other parameters of the model. Analysis was restricted to general parameter categories. In general, since the benefit from electrification is in savings in operating costs, increasing levels of cost escalation tend to increase the overall benefit. In addition, if there are higher escalation rates, operating cost savings of substantial magnitude are generated sooner, thus advancing the optimal timing for electrification. Similar effects are produced by a greater differential between the general cost-escalation rate and that applicable to operating cost components, e.g., diesel fuel.

Of all of the parameter groups investigated, prices of diesel fuel and electricity were found to have by far the most important impact on economic viability. Figure 6 plots the model's output for variations in the prices of diesel fuel and electricity. The base-case cost levels indicate the IPV of all the costs and savings over a theoretically infinite time period as a result of electrifying the hypothetical territory of 650 km. Each dot shows the IPV for a specific year in which electrification might be initiated.

Thus, for example, if electrification of this theoretical territory were initiated in 1978, the IPV for the entire stream of future savings, appropriately discounted, would amount to approximately $12 million. If electrification were deferred until 1986, the IPV of the future savings would be reduced to approximately $6 million. Thus, the methodology and model respond to the question of when might (or should) electrification occur. Obviously, from a savings standpoint, it should be initiated sooner.
about 1980, if the base case only included real
input for a specific operating segment. It is apparent
what would happen, however, if energy prices were to
be different from those used in the base case. If diesel
fuel prices were higher by 25 percent, electrification
should begin immediately, and the indicated IPV would
be in excess of $30 million.

Net savings in energy and locomotive maintenance
provided the major component of operating cost savings,
while catenary and other fixed-plant expenditures pro-
vided the major component of capital costs. Since cate-
nary, transmission lines, and other infrastructure cap-
tial costs are location specific, they must be estimated
individually for each candidate for electrification.

The results of the financial analysis clearly indicate
that a positive equivalent-present-value cost savings
can be attributed to the electrification of some segments
of the Canadian railway system. The analysis also indi-
cates however that, although an investment in electrifi-
cation may be economically attractive (have a positive
IPV) at 14 to 18 Tg (15 to 20 million tons), it might not
be considered commercially attractive. The model can
only evaluate the total benefits from cost savings. It
cannot tell how they will be distributed. If strong con-
sumer and political reactions left the railway with only
a small part of its total traffic, the change might be in
the national interest but unprofitable to the enterprise
that would normally make the investment.

It is important to note that a major capital commit-
ment may be a dangerously disproportionate burden if
traffic drops or any one of a number of other factors
becomes adverse. The burden accepted is immediate
and relatively definite; the benefits are indefinite and
distant in time. In effect, electrification exchanges the
variable costs of fuel and labor for the fixed cost of con-
version to electrification. This increases sensitivity to
cyclical swings in traffic, as well as to defects in the
traffic forecast, and therefore increases the risk of
construction process, which involves a high proportion
of relatively unskilled labor, would provide additional bene-
fits during a period of high unemployment, such as the
one we are facing at the present time. However, rail-
way electrification is not a simple process. The long
payback period makes the financial aspects less attrac-
tive.

Railways are faced with a number of alternative
methods to increase rail productivity, and all they re-
quire is capital. However, we believe that North Amer-
can railways can benefit significantly from rail electric-
fication, in much the same way that other railways
around the world have. On some rail lines, traffic is
already approaching levels that justify electrification.
As traffic increases, the interference caused by track-
side construction becomes more severe. Electrification
should therefore occur before critical levels have been
reached. Thus, in the Canadian situation, if electrifica-
tion is to occur, it cannot begin too soon. We suspect
that the United States is facing the same situation.

**Comment**

Per Erik Olson, ASEA, Inc., White Plains, New York

The adhesion values used in this report may be too
modest. If we at ASEA understood the figures correctly,
the suggestion was made to use not more than 635 kW/
axle, which gives 30 percent adhesion. A study carried
out by Canadian Pacific Ltd., using a Swedish locomotive
on the Norwegian State Railway in mountain areas, found
that the average adhesion achieved was about 30 percent
and could be increased (1). Use of the ASEA RC4 loco-
motive in the Northeast Corridor has clearly verified
that adhesion levels above 30 percent can be used with
an individual early warning system like that on the ASEA
locomotive.

**Author's Reply**

After reviewing the source data from the Canadian Pa-
cific study (1) and discussing the results with railway
personnel who are responsible for dispatching trains,
we concluded that, until substantial North American ex-
perience has confirmed the high adhesion capability of
European locomotives under North American conditions,
it would be too optimistic to assume that adhesion levels
of more than 30 percent can be achieved. Research per-
sonnel have suggested that the figure should be higher,
but some members of the Mechanical Department have
suggested much lower figures and are concerned about
the effects that high-adhesion locomotives will have on
wheel and track wear. There is no agreement.

Since adhesion characteristics may have important
consequences on the economics of electrification, it is
better to assume a lower value, recognizing that the
benefits may be increased as experience permits the
use of higher values. A full-scale prototype railway
operation under typical operating conditions would pro-
vide the experience necessary to establish an acceptable
level for dispatching purposes.

The matter of the optimum locomotive axle power is
an area that requires further investigation and is spe-
cific to the rail system under investigation. For Cana-
dian railways, 835 kW/axle is too low, but we suspect
that 1500 kW/axle is too high. The overload capability
of the electric locomotive further complicates this study.

Comment

J. K. Leslie, Canadian Pacific Ltd., Montreal, Quebec

What are the relative advantages and disadvantages of 50-kV and 25-kV operation, from the operation point of view?

Author's Reply

The size of catenary wire may be dictated by considerations of wire strength or by current capacity. The lightest practical catenary, on the basis of strength, would typically carry slightly more than 600 A. At 25 kV, such a catenary would limit train power to roughly 8.9 MW (12 000 hp) and impose severe restrictions on train spacing. A 50-kV catenary, with twice the power capacity, would entail fewer restrictions on train power and operation.

To avoid the train restrictions, a 25-kV catenary would be designed to handle more current. However, increased current requires larger wire sizes, which increases the cost of the 25-kV catenary. The increase in wire cost would, in most cases, be much more significant than the additional costs encountered in providing the electrical clearance and insulation required for the 50-kV system.

The current capacity of locomotive pantographs would require the use of three or four pantographs to handle the current demand for an 11.9 to 17.9-MW (16 000 to 24 000-hp) unit train (16 locomotive axles) operating at 25 kV. A 50-kV supply would reduce the number of operating pantographs required, thus reducing the dynamic interaction of the catenary with multiple pantographs. The reduced dynamic interplay in turn reduces the loss of contact and hence the loss of unit power and electric arcing, which reduces problems of train dynamics and catenary and pantograph contact wear.

The loss of voltage due to the impedance of the catenary wire is proportional to the distance from the supply point and the current carried. If the permissible voltage drop is limited, for example, to 10 percent of the nominal supply voltage, then a 50-kV substation might end feed a 32-km (20-mile) segment of catenary, but a 25-kV substation could only feed a 16-km (10-mile) segment. Thus, the 25-kV system requires twice as many substations and twice as many phase breaks. On the basis of substation and utility feed costs, the 50-kV system provides lower costs per kilometer.

The initial cost of constructing the 50-kV catenary system would be significantly lower than the cost of a 25-kV system, except in areas that require extensive public works related to tunnels and bridges. The operational effects of properly designed 25-kV and 50-kV systems would not differ significantly. The lower number of phase breaks of the 50-kV system would decrease the number of times the locomotive power had to be reduced to zero during a train run. The relative safety of 25 and 50-kV systems suggests no advantage—both are lethal, and both require comparable protection for workside wire structures.

Comment

J. K. Leslie

How does central dispatching reduce the power demand and hence the cost?

Author's Reply

Locomotives can be equipped with remotely operated power-limiting circuits as part of the normal power-control system. Each locomotive unit can be adjusted to respond to its unique code. This is similar to the practice used in robot midtrain power systems.

The coded limiting signals may be transmitted by radio or as carrier signals on the catenary system. Thus, it is possible to limit the power demand of each locomotive from a central power-control center. The train dispatcher in a centralized traffic control (CTC) territory is able to monitor the progress of individual trains within his territory from a central panel. The power control center should be made part of the CTC display or located immediately adjacent to it.

The electric demand charge is based on the peak power required over a certain period, typically 30 min, on a monthly basis. The power control center would display the system's instantaneous power demand, and an audible and visual alarm could indicate when the demand exceeds a preset level. The power dispatcher (perhaps the train dispatcher) could take action to reduce the power demand on appropriate locomotive units in order to limit the 15-min demand peak. This might involve reducing the power demand by 20 percent on a heavy train climbing a gradient at high speed, thereby slowing that particular train for a short period of time—only a few minutes.

Reply

Blair A. Ross, American Electric Power Service Corporation

It is believed that, although the use of central dispatching to reduce demand is valid in theory, it may be questionable in practice and would require careful analysis to determine whether the restraints on railway operation are worth the power-demand savings.

Comment

Keith Chirgwin, Garrett Corporation, Torrance, California

In relation to Figure 2, in which tractive effort was plotted against speed, and specifically with regard to curve c (poor rail conditions), I would like to ask:

1. How was this curve arrived at, i.e., what are the conditions or assumptions behind it?
2. What is the significance of the curve as far as locomotive operation is concerned?
3. How does this curve compare with similar curves
published by European locomotive suppliers that show higher values of tractive effort?

Author's Reply

Curve c in Figure 2 begins at 28 percent adhesion at 0 km/h. This point was selected after reviewing the data obtained in tests of the ASEA RC2 locomotive by Canadian Pacific Ltd. during the winter of 1970-1971. During these tests, the adhesion level dropped below 28 percent on fewer than 10 percent of the starts, and the second attempt to start was always successful. This seems to be an acceptable (but minimum) level for train scheduling for a modern electric locomotive of refined design on Canadian railways.

As locomotive speed increases, the dynamic effects tend to reduce the effective adhesion. This, of course, is a function of track structure, rail quality, and vehicle suspension. The curve used is similar to those used by European railways, and it is used for illustrative purposes only.

Canadian railway personnel suggest that the adhesion levels represented by curve c are optimistic. However, the larger wheel diameter, the use of shunt field-traction motors, improved wheel-slip controls, and improved locomotive suspensions all contribute to higher adhesion levels. We believe that levels corresponding to those in curve c can be achieved and would be used for heavy freight trains on Canadian railways after a suitable period of experience.

Curve c illustrates that, at low speeds, the full power of an electric locomotive cannot be used; it is limited by its adhesion. The high-power locomotive (1500 kW/axle) may not be power limited until the locomotive exceeds 96 km/h (60 mph).

REFERENCE