Interference of Electrification With Signaling and Communication Systems

Hugh C. Kendall, General Railway Signal Company, Rochester, New York

Signal and communication systems are an integral part of railroad operations and are essential to provide safe and expeditious train movements. The major functions performed by these systems are:

1. To maintain safe separation between trains and to detect unsafe conditions in the track ahead of a train, e.g., a broken rail, misaligned switch, open bridge, rock slide, or high water;
2. To detect unsafe conditions on cars and locomotives, e.g., overheated journal bearings (hotboxes), dragging equipment, broken flanges, loose wheels, or high, wide, or shifted loads; and
3. To increase the traffic capacity of a railroad through centralized traffic control and automated terminal control systems.

Signal and communication systems must function with utmost reliability under a wide range of environmental conditions and must also withstand the interference effects produced by commercial power systems along the right-of-way and, in the case of electrification, the additional interference effects produced by the propulsion power supply and the locomotives. It is reassuring to note that there have been signal and communication systems designed and currently in service both in this country and abroad that are fully capable of reliable operation under any or all of the above conditions. These systems are in general more complex and costly to install and maintain than those currently employed in non-electrified territory. Deciding whether to electrify a railroad does not therefore depend on the availability or lack of signal or communications technology but depends rather on its economic justification.

Those railroads that carry more than half of the freight traffic in this country, and therefore are logical candidates for electrification, have signal and communication systems that are for the most part complete, quite modern, well maintained and long lived. Without a very substantial increase in rail traffic, these facilities would not require alterations or additions. Unfortunately, the changes required to render these systems compatible with electrification represent a substantial expense that has very little economic justification in terms of increased safety or ease of railroad operations. In reality, it is an expense that a railroad must make solely because of electrification. The signal engineer is therefore in a difficult situation and is sometimes considered a roadblock to electrification. In the past, the signal engineer has only been able to make capital expenditures on the basis of sound economic justification. Electrification will require large sums of money just to recover the use of facilities that are already in service under diesel operations.

Open-wire lines along the right-of-way are generally used in nonelectrified territory for interconnecting various elements of the signal system, for transmitting power for battery-charging purposes, for transmitting commands and indications for centralized traffic control, and for the maintainer’s and dispatcher’s telephones and other communication purposes. Over the years, the signal-to-noise ratio in these circuits has been gradually degraded by the interference effects produced by high-voltage power lines that have been erected along the right-of-way. In some instances, it has been necessary to place these circuits in shielded cable to effect satisfactory coordination.

In electrifying a railroad, the interference effects are greatly compounded. The proximity of the catenary to the open-wire lines creates intolerable signal-to-noise ratios in these circuits and also increases the danger of shock to personnel. On this basis, these lines must be either eliminated or placed in suitably shielded cable.

Double-rail direct-current track circuits are generally used in nonelectrified territory to detect trains and broken rails. Insulated joints in the rails are required to isolate one track circuit from the next. In electrifying a railroad, the propulsion current flows through the rails on its return path to the substation. A means must therefore be provided for bypassing the insulated joints. The commonly accepted means for accomplishing this creates a low-resistance path between the rails at each end of the track circuit, just as the wheels of a train do. Double-rail direct-current track circuits
therefore cannot be employed in electrified territory. They must instead be replaced by suitable alternating-current track circuits.

The impact of the catenary system on parallel signal and communication circuits will be examined below in detail, along with the consequences of using the track for both return of the propulsion current and detection of trains and broken rails. The costs associated with rendering existing signal and communication systems compatible with the electrification environment will also be identified.

**SOURCES OF INTERFERENCE**

Signal and communication systems in alternating-current electrified territory must withstand substantial interference effects produced by current flowing in the catenary and the use of the rails to return the propulsion current. These interference effects may be conveniently divided into four categories:

1. Electromagnetic induction—the effect on a conductor produced by varying current flowing in a parallel conductor.
2. Electrostatic induction—the effect on a conductor produced when another conductor has a higher potential than the ground.
3. Rise in ground potential—the effect produced by the use of the ground as a conductor.
4. Metallic cross-conduction—the effect produced by the accidental connection of one conductor to another.

**Electromagnetic Induction**

Alternating current flowing in the catenary produces an alternating magnetic field around the catenary. The strength of the magnetic field is directly proportional to the current, and it decreases as a function of distance from the catenary. The alternating magnetic field induces an alternating voltage of the same frequency in any conductor that parallels the catenary regardless of whether the conductor is above or below ground. The induced voltage is proportional to the strength of the magnetic field, the frequency, and the length of parallel exposure.

Figure 1 shows the voltage that would be induced in a conductor 1 km (0.6 mile) long that paralleled a catenary carrying a current of 1000 A at 60 Hz, assuming that the propulsion current returns to the substation via a remote-return path. Note that a conductor separated from the catenary by a distance of 9 m (30 ft) would experience a longitudinally induced voltage of approximately 375 V. If this conductor became grounded at one end, an open-circuit potential of 375 V would appear between the other end of the conductor and the ground.

In Figure 1, the effect of the magnetic field produced by the return of the propulsion current was neglected in the interest of simplicity. In reality, this field has an important bearing on the actual voltage that is induced on conductors paralleling the catenary. Figure 2 assumes that all of the propulsion current returns to the substation via the rails. The current flowing in the rails is in phase with the current in the catenary but flows in the opposite direction. The two magnetic fields therefore tend to offset each other in a midway neutral plane. If one were to locate a conductor parallel to the catenary in the neutral plane, no voltage would be magnetically induced in it. If the conductor were located either above or below the neutral plane, the voltage induced in it would vary as shown. At a distance of 9 m from the catenary, for instance, if the conductor were raised to the height of the catenary, approximately 25 V/km (40 V/mile) would be induced in it. This is a substantial reduction from the case seen in Figure 1.

Unfortunately, not all of the propulsion current returns to the substation via the rails. The rails of a track structure are in close contact with the ballast, which creates leakage paths between the rails and the ground. It is not uncommon for the resistance between the rails and the ground to measure less than 1 Ω in a typical track circuit. In an electrified railroad, therefore, a portion of the returning propulsion current leaves the rails and flows back to the substation via a ground path.

Due to the character of the ground as a conductor, the phase angle of the returning propulsion current flowing in the ground path differs from that flowing in the rails, which tends to reduce the neutralizing effect of the ground current field on the catenary current field. Furthermore, the effective ground return path is generally far removed from the catenary, with the depth of the path in the earth dependent on the earth's resistivity and also on the distance between a given locomotive and the substation. When this distance is large, a substantial portion of the returning propulsion current flows in the ground path.

If one were to assume in Figure 2 that half of the returning propulsion current flowed in a ground path at a depth of 75 m (246 ft) below the catenary, with the other half flowing in the rails, it would be reasonable to expect a longitudinally induced voltage of about 125 V/km (200 V/mile) in a conductor that was 9 m away from the catenary. One means of reducing the induced voltage over long distances is to use a three-wire system with autotransformers and a negative feeder, as shown in Figure 3. This arrangement minimizes the induced voltage in the unoccupied sections between the substation and the autotransformers where the return current flows through the negative feeder, and the rail and ground currents are negligible. With an autotransformer that has a 2:1 ratio, the catenary and negative feeder current carry only half of the load current, and the negative feeder effectively shields parallel conductors near the neutral plane.

In the above examples, a catenary current of 1000 A at 60 Hz was assumed. This current might not be exceeded under normal operations on a railroad that has been electrified at 25 kV and undoubtedly would be well above that required in a 50-kV operation. It should be borne in mind, however, that a fault in the propulsion system could create a temporary catenary current of as much as 10 times normal amperage. Under these circumstances, voltages induced in parallel conductors could rise to as much as 10 times their normal values. In the event of a fault, however, the hazards to personnel must still be kept within acceptable voltage limits, and damage or malfunctions in signal or communication equipment must not be allowed to occur. In no case can the safety to railroad operations be compromised under such circumstances.

The effects of electromagnetic induction on conductors that parallel the right-of-way can be reduced to tolerable limits by placing these conductors in shielded cable wrapped with ferrous tape with the shield grounded at frequent intervals. The cable may be either buried or laid in trunking along the right-of-way and should preferably be laid as far as practical from the track. A properly designed and installed cable can reduce the effects of electromagnetic induction by as much as 95 percent. Unfortunately, however, conductors that are not under railroad control frequently parallel the right-of-way. A farmer's fence or local communication lines are typical examples of this. They constitute a hazardous liability to an electrified railroad, and adequate steps must be taken to ensure the proper grounding or shielding of these facilities.
Regardless of whether current is flowing in the catenary, open-wire lines along the right-of-way that have significant capacitive coupling to the catenary will experience the effects of electrostatic induction by virtue of the fact that the catenary has higher potential than the ground. In the event such lines became open circuited at both ends, it would not be unreasonable to find several hundred volts electrostatically induced in them in high-voltage electrified territory. The potential to which they would rise would depend on the relative capacitance between the lines and the catenary and the lines and ground, as shown in Figure 4. The effects of electrostatic induction on open-wire lines can be eliminated by the use of shielded cable.

Metallic objects on the wayside also have significant capacitive coupling to the catenary and, if ungrounded, could rise to several hundred volts above the ground, creating a shock hazard to personnel. Adequate steps must therefore be taken to see that all such objects are adequately grounded. As in the case of electromagnetic induction, the influence of the electrostatic field of the catenary can extend beyond the right-of-way. A metal
with the ground, e.g., track circuits and cable shields, proven to be the simplest and most dependable means to protect personnel from the consequences of such an accident in ground potential.

Rise in Ground Potential

Propulsion current returning in the ground path to the substation creates a potential gradient near the surface of the earth. The potential gradient causes foreign current to flow in any conductors that are in good contact with the ground, e.g., track circuits and cable shields, as shown in Figure 5. Track-circuit coupling equipment must be rugged enough to withstand the foreign current that may flow through it. Cable shields must be adequate in conductivity to carry foreign current flowing in them because of the difference in ground potential along the right-of-way. Wayside housings must be grounded to minimize the hazard to personnel due to the difference in ground potential between wayside locations. Equipment in wayside housings must be protected from surges that originate in the cable system because of faults in the propulsion system.

Metallic Cross-Conduction

A catenary energized at 25 or 50 kV and barely 7.5 m (25 ft) above the rails poses a significant hazard to personnel and to wayside equipment in the event of a mechanical failure in the catenary that would cause it to drop and come into contact with elements of the signal or communication system. Conductors mounted on the catenary support poles, wayside housings, signal heads, wayside sensing equipment, and the rails themselves must be thoroughly grounded, and suitable protective devices must be installed in all wayside cases to protect personnel from the consequences of such an accident.

TRACK CIRCUITS

In nonelectrified territory, the neutral direct-current track circuit shown in Figure 6 has been the backbone of railway signaling for more than 100 years. It has proven to be the simplest and most dependable means ever devised to continuously detect the presence of a train between two points on a railroad. Insulated joints are used to isolate one track circuit from the next. The track relay (TR) at one end of the circuit is energized through the rails by a battery at the other end of the circuit. The track-circuit current flows from the positive terminal of the battery through a series circuit consisting of a battery-current-limiting resistor, the upper rail, the relay resistor, the relay coil, and the lower rail back to the negative terminal of the battery. A break in either rail or the failure of the battery, either resistor, or the relay coil will interrupt the flow of current and cause the front contact of the track relay to open.

The effect of the presence of a train on the track circuit is shown in Figure 7. The front wheels and axle of the locomotive shunt the two rails together, robbing the track relay of battery energy. The track-circuit current now flows through the front axle of the locomotive rather than through the relay coil, causing the front contact of the track relay to close. As mentioned previously, leakage paths exist between the rails because the rails come in contact with the ballast, as shown in Figure 8. For this reason, the length of a neutral direct-current track circuit is generally limited to 1.8 to 2.4 km (6000 to 8000 ft), depending on the ballast leakage conditions.

One means of lengthening a direct-current track circuit is to code the battery energy at one end and use a code-responsive (CR) relay at the other end as shown in Figure 9. The front contact of a code-transmitting (CT) relay is placed between the positive terminal of the battery and the battery-current-limiting resistor. In one type of circuit, the CR relay is operated by coding equipment in such a way that battery energy is alternately applied and removed from the track circuit for approximately equal intervals at a rate of 75 times/min. The CR relay at the other end of the track circuit alternately opens and then resets itself in response to the coded energy. A track relay is maintained in an energized condition by decoding equipment as long as the CR relay continues to operate. A broken rail, a train shunt, or a failure of any component in the circuit will cause the CR relay to stop coding and thus cause the track relay to release.

In electrifying a railroad, the domain of the track circuit is invaded by propulsion current on its return to the substation. Figure 10 shows an alternating-current track circuit that is suitable for use on railroads that have been electrified using high-voltage alternating-current. Note that the propulsion current flows down both rails in the same direction, whereas the track-circuit current flows down one rail and back on the other. Since insulated joints, if they were not bypassed, would block the flow of propulsion current between adjacent track circuits, an impedance bond is used at each end of the track circuit to form the path for the propulsion current.

As Figure 10 shows, an impedance bond is a center-tapped coil wound on an iron core. The ends of the coil are connected to the rails near the insulated joints, and the center tap is connected to the center tap of a similar bond in the adjacent track circuit. The path of the propulsion current through each half of each bond is in the same direction, that is, either toward the center tap or away from it. On this basis, because of flux cancellation, it encounters a very small impedance in passing from one track circuit to the next. Since the alternating track current flows through each half of each bond in the opposite direction, it encounters an impedance of several ohms. The effect of this impedance is to create a voltage drop across the bond, and therefore between the rails, that is sufficient to detect a train shunt when it occurs. A vane-like track relay is employed that requires two-phase related sources of energy to operate. One source is called the track phase and is transmitted over the rails. The other is called the reference phase and is transmitted over a pair of wires that run the length of the track circuit. If both sources of energy are present in the two coils of the relay in the proper phase, the front contact of the relay will close. A train shunt robs the relay of the track phase, thus causing the front contact of the relay to open. As with the direct-current track circuit, a failure of the energy source, the reference, or any component in the circuit will cause the track relay to open its front contact.

The alternating-current track circuit is energized at a frequency that is not harmonically related to the odd harmonics of the propulsion power supply. Because of the reactance of the rails, it is desirable to energize the circuit at a frequency that is as low as possible in order to maximize the length of the circuit. On railroads that have been electrified at either 25 or 60 Hz, a track-circuit frequency of 100 Hz has proven to be a satisfactory compromise. At this frequency, circuit lengths of
1.5 to 1.8 km (5000 to 6000 ft) may be used.

On certain railroads that are candidates for electrification, cab signals and overspeed control are used on locomotives. The systems use coded alternating-current in the track to convey information from the wayside to the locomotives. Where direct-current track circuits are used, coded alternating current is superimposed on the direct current. Figure 11 shows a coded alternating-current track circuit that is suitable for cab signaling in alternating-current electrified territory. It is essentially a modification of the alternating-current track circuit shown in Figure 10.

A front contact of a CT relay has been inserted in the track energy feed. The CT relay is operated at various code rates (75, 120, or 180 pulses/min) by the coding equipment, depending on the conditions on the track ahead. At the receiving end of the circuit, coded energy from the track is fed to one of two inputs of a phase-selective detector. Uncoded energy from the phase reference line is fed to the other input of the detector. When energy from the track is present in the proper phase at the detector, the CR relay is operated. When energy in the proper phase from the track is absent, the CR relay is released. As long as the CR relay responds to one of the three code rates, a track relay is maintained in an energized condition by local decoding equipment. Like the coded direct-current track circuit, a train shunt, broken rail, or failure in any component of the circuit causes the CR relay to stop coding and thus causes the track relay to release.

Aboard the locomotive, two receiving coils are mounted ahead of the front axle of the locomotive, as shown in Figure 12. The magnetic field around the rails produced by the track-circuit current induces a voltage in the receiving coils that is amplified and passed on to decoders, which determine the cab-signal aspect to be displayed in the cab as well as the speed-limit threshold of the overspeed governor. The actual speed of the locomotive is determined by a tachometer generator driven by an axle of the locomotive. If the speed of the locomotive exceeds the speed-limit threshold of the overspeed governor, an audible warning is sounded in the locomotive cab. If the engineman fails to take action within a prescribed time period, the locomotive's brakes are automatically applied until the speed of the locomotive is below the speed-limit threshold.

CONVERSION TASKS

The following tasks must be accomplished in rendering
existing signal and communication systems compatible with high-voltage electrification at either 25 or 60 Hz.

1. Neutral or coded direct-current track circuits must be replaced by either two-phase continuously energized or coded double-rail alternating-current track circuits that have impedance bonds. Experience has shown that a track-circuit energization frequency of 100 Hz can be used satisfactorily in these circuits for operating lengths up to 1.5 to 1.8 km (5000 to 6000 ft). Means must be provided to generate energy at the track-circuit frequency and to transmit it in a metallic circuit the entire length of the railroad.

2. Open-wire signal and communication circuits along the right-of-way must be replaced by shielded cable that is either buried or laid in trunking as far away from the track as possible. The interconnection of various elements of the signal system requires access to circuits in the signal cable at roughly 1.6-km (1-mile) intervals. This requirement in some respects precludes the use of a joint signal-and-communications cable. Communication circuits are generally designed for the long haul and, since they use relatively low signal levels, it is preferable not to open the cable any more frequently than is absolutely necessary. It is therefore customary to use two separate cables, but these cables can be buried in the same trench or duct running the length of the railroad. The use of cables requires that cable repeaters be installed at appropriate locations along the right-of-way to maintain satisfactory signal-to-noise ratios.

3. Instrument housings, signals, wayside detection devices, switch machines, and all other metallic objects along the right-of-way must be adequately grounded. In addition large metallic objects, fences, or wire lines that are off the right-of-way but relatively close must be either grounded or suitably coordinated with the propulsion power supply.

4. Surge arrestors and other protective devices must be installed in wayside cases to protect personnel and equipment if the propulsion power supply becomes faulty.

5. Signal cases and bungalows along the right-of-way must be supplied with power for battery charging, track-circuit energization, environmental control, and other purposes. In nonelectrified territory, a single-phase power circuit is conventionally carried on the open-wire signal and communication pole line along the right-of-way. With the elimination of the pole line, alternate arrangements for signal power must be made. One alternative would be to provide a signal power line carried on the catenary poles and energized from a substation. The signal power line would be operated at a voltage 25 to 50 percent that of the catenary voltage and insulated to withstand the effects of electrostatic induction on the catenary in the event the signal power line became open circuited. Transformers would be used at each signal location to step the power down to 110 or 240 V.

6. Rail bonding and cross bonding must be adequate to support both the propulsion and signal systems. Since traction bonds are required, this task is generally considered to be a part of the installation of the propulsion system.

7. If switch circuit controllers are used to shunt the rails, they must be suitable for heavy duty to withstand the possible unequal flow of propulsion current in the two rails.

8. Centralized traffic control systems generally use direct-current coding systems to convey commands to field locations and to receive indications from the field. The code lines parallel the railroad for very substantial distances without a break and could therefore have a relatively high exposure to interference effects produced by the propulsion system. In some cases, these code lines will have to either be broken and replaced by direct-current code repeater stations or be converted to carrier operation.

9. Signals that are now mounted on wayside poles would be obscured in some cases by the catenary support structures; such signals would require relocation to achieve adequate visibility. In addition, some signals are mounted on signal bridges that will have to be raised.
to permit the catenary to be installed.

10. The conversion of the signal and communication systems for electrification would involve the handling of substantial quantities of high-grade electrical equipment, housings, and cables along hundreds of kilometers of right-of-way. The movement, storage, and protection of this material during installation are an important task.

11. Cab signals are used on some railroads in non-electrified territory. In these cases, a coded 60-Hz signal is superimposed on the direct-current track circuit. In the event of electrification, the locomotive-carried equipment would require conversion for operation at the new 100-Hz coded track-circuit frequency.

12. Highway-crossing warning systems frequently use overlay track circuits to detect the presence of trains in the approach sections. In addition, motion detectors and constant-warning-time devices are employed in certain installations. In general, this track-connected equipment was designed for use in nonelectrified territory in which direct-current track circuits are employed. Under electrification, this equipment will usually require either modification or replacement to enable it to operate in the presence of 100-Hz track current and the higher harmonics of the 60-Hz propulsion current flowing in the rails. Since the number and complexity of highway-crossing warning systems on railroads vary widely in different parts of the country, the task of converting this equipment for electrification is generally considered as a separate item.

COSTS OF CONVERSION

During the past 5 years a number of railroads have conducted electrification studies. Some of the results of these studies have been made public, particularly those from the Consolidated Rail Corporation studies. Representative costs per kilometer for the conversion of signal and communication systems can be summarized as follows for a double-track railroad that is to be electrified at 25 to 50 kV 60 Hz:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal cable</td>
<td>4 000</td>
</tr>
<tr>
<td>Communication cable</td>
<td>3 000</td>
</tr>
<tr>
<td>Cable trenching and splicing</td>
<td>16 000</td>
</tr>
<tr>
<td>Signal power line and transformers</td>
<td>2 100</td>
</tr>
<tr>
<td>Impedance bonds</td>
<td>4 500</td>
</tr>
<tr>
<td>Moving signals</td>
<td>1 200</td>
</tr>
<tr>
<td>Prewired cases (track-circuit control)</td>
<td>12 000</td>
</tr>
<tr>
<td>Cabling and grounding of cases and signals</td>
<td>2 400</td>
</tr>
<tr>
<td>Modifications to hotbox detectors</td>
<td>300</td>
</tr>
<tr>
<td>Carrier repeaters and terminations</td>
<td>2 000</td>
</tr>
<tr>
<td>Material handling and security</td>
<td>3 000</td>
</tr>
<tr>
<td>Fence grounding</td>
<td>300</td>
</tr>
<tr>
<td>Testing and miscellaneous</td>
<td>2 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52 800</strong></td>
</tr>
</tbody>
</table>

The above figures do not include the costs associated with the conversion of track-connected equipment associated with highway-crossing warning systems, since the number of such systems per kilometer varies widely in different parts of the country. Also not considered are the costs of compatible track circuits within interlockings or those associated with sidings, since the quantity would depend on the layout of a particular railroad.

Comment

A. H. Carter, Bell Laboratories, Whippany, New Jersey

Kendall has discussed the interference effects produced in railroad signal and communication systems, noting that special problems are presented by the proposed conversion to 25-kV 60-Hz electrification. Interference with telecommunication systems is also likely to occur as a result of two factors.

First, at 25 Hz, interference is largely confined to the railroad right-of-way because it is produced solely by currents flowing in the catenary, the rails, and the earth. The commercial power system does not provide a path for current flow because it is electrically isolated from the catenary. The conversion to 60-Hz commercial power, on the other hand, will give rise to a proliferation of the interference in the local power distribution network and may necessitate inductive coordination extending beyond the right-of-way. The severity of the problem will depend on the extent to which the locomotive's rectifier harmonics flow back into the alternating-current network where communications and power lines are together on joint-use utility poles or in common trenches.

The second source of concern has to do with the wave shape of the induced currents. The action of the locomotive rectifier produces currents rich in harmonics of the fundamental power frequency. More harmonic energy lies in the voice-frequency band of telephone circuits with 60-Hz power than with 25 Hz; thus the noise generated is expected to be correspondingly greater. Experience has shown that the noise problem is manageable if the interfering system's I-T product is less than about 20 kA (the I-T product is the product of the total current and the telephone influence factor, a dimensionless quantity that describes the frequency distribution of the harmonic components of the rectifier current within the voice-frequency spectrum, weighted according to the response of the telephone set and the auditory characteristics of the user). Predictions based on limited measurements of wave forms of locomotive rectifiers give I-T products that are an order of magnitude higher for 25-kV 60-Hz systems, implying an increase in noise levels of approximately 20 dB. Such an increase would undoubtedly entail inductive coordination or mitigation requiring modification of both railroad and telephone systems in many situations.

At present the Bell System is engaged in a program to assess the magnitude of the potential problem. As a first step, measurements of rectifier current and induced voltage are being made in cooperation with the Muskingum Electric Railroad, which operates E-50 locomotives on 25-kV 60-Hz power. The results of these studies will be reported through the TRB Committee on Electrification Systems.

Reply

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Carter comments that 60-Hz electrified railways interfere with commercial telecommunication systems, as well as with railway signal and communication systems, and that this must be recognized. As was indicated in the discussion, the locomotive rectifiers are the primary source of the interference. The problem of harmonic re-
Impact of Research and Development on Railroad Electrification

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The 1974 report of the government and industry task force on railroad electrification (1) concluded that electrification is the only available alternative to diesel-electric operation and that railroad electrification offers the only feasible means to use coal or nuclear energy for intercity movements of general freight and passengers. However, the investment required is not so attractive as to cause immediate conversion of the nation's rail system from diesel-electric to electrified operation, particularly considering the present state of railroad finances. By contrast, enormous savings were possible at the turn of the century by converting from steam to electric motive power, and even greater savings were realized in the 1940s by converting from steam to diesel-electric motive power.

Electrified operation has its place in the nation's rail system, not as a replacement for diesel operation but as a partner in the effort to provide the most efficient means of transporting freight and passengers. It is generally accepted that, above a certain level of traffic density, electric traction provides lower operating costs. However, it is essential that the traffic forecasts predict with some assurance that the route will maintain sufficient density over the life of the traction equipment to justify the large capital investment.

Specific conditions may make electrification more attractive financially. For example, the availability of low-cost hydroelectric power, the short-term high-power demands of mountainous routes or schedules with frequent acceleration requirements, and the requirement to eliminate emissions in tunnels and urban areas are characteristics that were influential in the decision to electrify specific routes in the United States and Europe.

Other conditions have the effect of forcing a decision to be made concerning electrification. The scarcity of fuel and the limitations on diesel-engine development are two cases in point. It should be emphasized that the scarcity of fuel does not imply that fuel is not available to the railroads of the United States. Their consumption makes up only a small percentage of the total oil consumption and could always be accommodated, but the uncertainty about the cost of fuel affects the capability of the railroads to develop long-range growth plans. The upper limit on diesel locomotive power appears to have been reached, just as it was with the steam locomotive. Railroads now use up to 12-unit consists for high-speed intercity movements of general freight and passengers. However, the investment required is not so attractive as to cause immediate conversion of the nation's rail system from diesel-electric to electrified operation, particularly considering the present state of railroad finances. By contrast, enormous savings were possible at the turn of the century by converting from steam to electric motive power, and even greater savings were realized in the 1940s by converting from steam to diesel-electric motive power.

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Other conditions have the effect of forcing a decision to be made concerning electrification. The scarcity of fuel and the limitations on diesel-engine development are two cases in point. It should be emphasized that the scarcity of fuel does not imply that fuel is not available to the railroads of the United States. Their consumption makes up only a small percentage of the total oil consumption and could always be accommodated, but the uncertainty about the cost of fuel affects the capability of the railroads to develop long-range growth plans. The upper limit on diesel locomotive power appears to have been reached, just as it was with the steam locomotive. Railroads now use up to 12-unit consists for the very long trains. Attempts to increase engine power have resulted in losses in reliability and higher maintenance costs. The electric locomotive, with its higher power density and overload capability, gives the railroads the capability to offer increased service as the economic demands of the market develop.

The Railroad Revitalization and Regulatory Reform Act of 1976 is expected to result in a major reassessment of electrification and its impact on railroad operations in the United States. A direct impact is the major rehabilitation by the National Railroad Passenger Corporation (Amtrak) of existing electrification and the extension of electrification to cover the entire Northeast Corridor (Washington to Boston) for high-speed passenger operations. Specific provisions of the act enable the Consolidated Rail Corporation (Conrail) to request from the Secretary of Transportation a federal guarantee for loans for funds to electrify high-density main-line freight routes. Other railroads have informally notified the Federal Railroad Administration (FRA) that they wish to apply for electrification funding under other provisions of the act.

A sector of the Conrail track that has been given consideration for electrification is the route from Pittsburgh to Harrisburg, which has the highest traffic density in the United States. Because the Conrail route from Harrisburg east to the Northeast Corridor (run by Amtrak) is already electrified, the new wiring represents an extension of electrification. Upgrading of the Northeast Corridor will force Conrail to decide between upgrading of current electrification equipment and replacing the existing electric fleet with a diesel fleet. It is probable that the decision to continue electrified operation would include the recommendation to extend electrification from Harrisburg to Pittsburgh.

Site-specific studies are required to determine whether there are other routes that would be better served by electric traction. It is not the purpose of this report to expound on the methodology of evaluating motive-power alternatives in an electrification feasibility study. Suffice it to say that each application must be examined very carefully to assure that the multitude of design and cost factors are estimated with sufficient accuracy to make the result convincing. The uniqueness of each site study is reflected in the relative influence of such factors as fleet size, energy costs, and the effect on public works, all of which can have a major impact on the investment decision.

Electrification of U.S. railroads could begin immediately if the existing technology from the European, Russian, and Japanese rail systems were adapted. This assumes that design variations resulting from the uniqueness of U.S. railroads are minimal. However, the long-