Implementing an Electrification Program: The Northeast Corridor Improvement Project

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The Northeast Corridor Improvement Project is providing an opportunity, unparalleled in almost two generations, for the implementation of a railroad electrification system in North America.

As we all are acutely aware, there has been limited effort toward electrification in this country; the Black Mesa and Lake Powell Railroad and one or two other single-track, short-haul unit train lines have been constructed within the last few years. Other contemporary activities have encompassed only modifications to existing systems, such as the conversion to 60-Hz frequency between New Haven and New Rochelle (now under construction through the efforts of the Transportation Authority of the states of New York and Connecticut in conjunction with their suburban passenger-train improvement program) and a large freight-yard revision now under construction at the Potomac Yard in Alexandria, Virginia.

The Northeast Corridor Improvement Project, in fact, deals with two major and distinct electrification program objectives. The first is the planning, design, and construction of an entirely new system between New Haven and Boston, and the second involves conversion and rehabilitation of the existing system between Washington and New Haven. In order to set the scene for further explanation of this project and for those who may not be totally familiar with the Northeast Corridor situation, I shall briefly describe the existing layout.

The Northeast Corridor is 734 km (456 miles) long. The route from Washington to New York City covers 364 km (226 miles) of essentially multiple track. It then traverses more than 30 km (20 miles) of the double-track Hellgate Line to New Rochelle, New York. The system is electrified over this total distance, using 11.5-kV 25-Hz propulsion through fixed-anchorage compound catenary. High-voltage transmission lines are also an essential part of this system. In the 87 km (54 miles) of four-track line between New Rochelle and New Haven, a power-supply conversion project to 12.5 kV 60 Hz is now under construction. The catenary throughout this territory is of the oldest vintage; it dates back to the early 1900s. The balance of the 251 km (156 miles) of double track between New Haven and Boston is not electrified.

As a result of extensive engineering and cost-effectiveness studies, it has been recommended to the Secretary of Transportation that this entire system be designed and constructed to facilitate 25-kV 60-Hz operation. This includes the conversion of the existing 11.5-kV 25-Hz propulsion between New Rochelle and Washington and the 12.5-kV 60-Hz operation now being implemented from New Rochelle to New Haven.

Before further discussing the project implementation plans, I would like to examine the basic technological and economic issues that led to their selection.

UNDERLYING TECHNOLOGICAL AND ECONOMIC ISSUES

Previous studies have largely shown that, beyond question, dense high-speed intercity passenger service is most economically operated with electric propulsion. Given this premise, it was then necessary to decide whether to reconstruct the existing system and extend it to Boston or to modify and rehabilitate it for a different voltage or frequency. Throughout the analyses it had to be remembered that the Northeast Corridor was established as a system and should not have different electric subsystems unless economic reasons become overpowering. The primary factors considered in the analyses were the

1. Normal and peak power requirements for each train, as well as all passenger-service and freight trains;
2. Speed requirements and number of pantographs;
3. Current transfer limits between wire and pantographs;
4. Voltage-drop limitations;
5. Climatic conditions;
6. Impact on vehicles, signals, communications, and so on; and
7. Operating and maintenance costs.

The most basic requirement was that sufficient power should be available to provide reliable service at speeds that would meet the travel-time goals set forth by the Railroad Revitalization and Regulatory Reform Act without setting unmanageable constraints on the size or frequency of trains. The electrification system was also expected to last at least 30 years after the completion of the project. Analysis of patronage demand showed a potential need for trains of as many as 14 cars at 15-min headways on some segments of the system. These trains would need a tractive effort (using up to three locomotives) capable of sustaining a cruising speed of 190 km/h (120 mph), with the maximum power demand occurring during acceleration at between 55 and 130 km/h (35 and 80 mph). Under these conditions the existing minimal propulsion supply (at any frequency) would require about 3.2 kA at 12.5 kV. This is nearly double the safe wire-annealing limit of the existing catenary. To enable trains to draw power of this magnitude, therefore, the voltage must be raised or the diameter of the wire must be significantly increased.

The other basic consideration was the power-capacity requirement for each substation projected for a typical schedule of trains (commuter, long-haul, high-speed intercity, and freight trains). Projections of patronage demand for 1981 and 1990 were derived through the use of a train consist and schedule simulation program adapted to provide data on power requirements. As might be surmised, the demand far exceeded the existing installed capacity of the existing individual substations and converter stations. Adding the requirement of a 30-year future life for the existing substations to the power-demand projections strengthened the argument for complete replacement on all existing substations.

The problem of capacity, as it applied to the costs of catenary and the power supply and as it is affected by a change in voltage and frequency, was then considered in one economic equation. Increasing the voltage to 25 or 50 kV would permit using the existing catenary with no change to the wires, but it would require greater overhead clearances. The option for 50 kV was discarded when it was determined that it could not be installed within the clearances of the New York tunnels or a majority of the 515 overhead bridges that exist along the route.

It was also found that new 50-kV catenary was no more economical than 25-kV catenary because the diameter of wire needed to satisfy mechanical loading problems of wind and ice, together with the high tension required to satisfy speed criteria, exceeded the requirements for the electrical capacity.

Since the existing system was constructed with double insulation (to compensate for steam engine exhaust), the voltage could be doubled to 25 kV with only minor modifications in some places where the clearance was tight. On the other hand, any voltage increase would require modifying to some extent most vehicles that use the Northeast Corridor, and these costs would have to be added. It also should be recognized at this point that, under any alternative, replacement vehicles would be required for the GG-1s and old commuter cars, which are considered uneconomical to convert.

Thus, since vehicles would have to be modified for a voltage change, the potential for conversion to a commercial frequency was further evaluated. The use of 25-kV 60-Hz power would eliminate the need to build and install new frequency converters, step-up transformers, and new high-voltage transmission lines over the railroad from New Haven to Boston and would eliminate the requirement to install additional frequency converters, step-up transformers, associated switching gear, and protection devices, as well as to replace the old existing units, transmission lines, and impedance bonds between Washington and New Rochelle. Considering all these factors, including the number of substations and the flexibility of using commercial power, the results favored a frequency change and higher voltage.

Finally, the existing fixed-anchorage catenary system from New Haven to Washington was analyzed for sustained high-speed performance. Temperature-induced tension variations were established as the prime factor in the ability of this existing system to perform, particularly under reaction to high temperatures. It was determined that, if the voltage were increased to 25 kV, the resulting current-induced temperature increase would be at acceptable levels for continuous speeds of 190 km/h (120 mph). In addition, the hangers adjacent to the supports would have to be modified, in conjunction with wire retensioning and selected reprofiling at "hard spots" (places at which the catenary has less flexibility and greater resistance to upward movement). The reliability needed to sustain higher speed ranges in the future would require conversion to a system using constant tension.

DESIGN AND CONSTRUCTION COSTS

For the new system between New Haven and Boston it was determined that the difference in design and construction cost between a new 240-km/h (150-mph) catenary system and a new 190-km/h (120-mph) design was negligible. It was therefore decided to make the new catenary system from New Haven to Boston capable of sustaining operations at 240 km/h (150 mph) by three power units. The new catenary will be of a compound style with constant tension, telescopic hangers, and a typical span length of about 64 m (210 ft) in territory without curves. A simple-catenary version of this design will be used in heavily curved segments, where speed cannot exceed 160 km/h (100 mph) without track realignment. Yards and complex terminal trackage will be equipped with a simple catenary or possibly only trolley wire with fixed anchorage, since speed is of no concern.

To turn to the economics of these analyses, the 25-kV 60-Hz electrification program that has just been delineated would involve the following estimated costs on the basis of a schedule projected to 1990:

Subsystem Component	Cost ($000 000s)
Catenary	113
Substations	69
Conversion equipment	–
Transmission	31
Other required modifications	
Bridges	32
Tunnels	5
Signals	70
Rolling stock	79
Subtotal	399
Replacement vehicles	173
Grand total	572

The $399 million projected cost can then be compared with the costs for two of the alternative systems evaluated.

System	Project Cost Without Replacement Vehicles ($000 000s)	Annual Maintenance Cost ($000 000s)
12.5 kV 60 Hz	541	8
12.5 kV 25 and 60 Hz	532	11
25 kV 60 Hz	399	5

The comparison shows an approximate first-cost advantage to the 25-kV 60-Hz system of 20 to 25 percent. Since the projected maintenance costs are also significantly lower, there is a good basis for recommending this system.

With the system engineering part of the project fairly well along at this time, the implementation of the program is proceeding on several other fronts in preparation for making the final design subcontracts.

Work is now in progress on such typical project elements as the development of a commercial power-supply service and the establishment of a service agreement, the location of substations and identification of equipment requirements, location of the switching stations and their equipment, finalizing the power-demand analysis, completion of bridge and tunnel clearance surveys, rehabilitation survey of the existing catenary system and the tensioning requirements, establishing design standards and specifications for catenary, establishing the pantograph type, developing a high-speed phase-break assembly, providing an outline design of poles and headspan assemblies, determining the outline requirements of the supervisory control system, providing the interface with the signals and communications facilities, performing an interference survey and determining the requirements for its mitigation, establishing a preliminary layout for track configuration, and making preliminary studies for the power-factor conversion equipment and mitigation of harmonics.

The most complex of these basic elements is the establishment of the commercial power-supply system. The decision to use a 25-kV 60-Hz power supply entails many additional problems in arranging commercial delivery to each of the approximately 36 substation locations from 10 different power companies between Washington and Boston. Engineering studies are now in progress to determine the best locations for the substations and the power supply points by using cost-effective tradeoffs between the power-supply requirements and geographic location, e.g., the possibility of locating a substation at an existing high-voltage right-of-way crossing location or providing more right-of-way transmission rather than constructing a new high-voltage branch across country to the substation location. There are 20 substations between New York and Washington. It is hoped that these supply points can be established at existing substation locations in order to minimize the potential for new environmental intrusions.

Between New York and New Haven there are 6 substation locations, while between New Haven and Boston there are 10 or 11 new substations to be constructed. The substations are standardized to provide a continuous power rating of 15 to 30 MV·A. Each will occupy an area approximately 20 m by 14 m (65 ft by 45 ft), and they will be approximately 16 to 19 km (10 to 12 miles) apart. The supply system to the catenary will use a center feed. Thirty-five switching stations will be located midway between the substations.

ENVIRONMENTAL IMPACT

The most important institutional requirement for the current phase of the electrification program is also in progress. An environmental impact statement for the Northeast Corridor Improvement Project will be published shortly, followed by public hearings within a few weeks. This document addresses the environmental issues involved in the proposed electrification along with its accompanying subsystems.

Potential impacts are being identified and evaluated as the various program requirements are identified. As conflicts are recognized through this procedure, engineering designs are evaluated for mitigating solutions, which are then applied. It is through this process that we hope to achieve maximum sensitivity of design and construction to the environment and, thereby, acceptance from the public sector.

There are obvious potential conflicts, particularly from New Haven to Boston along the coastline, where the catenary structures will cause aesthetic intrusions into the natural background. However, it is hoped that, since they are documented in the environmental impact statement, the advantages that will result from implementation of the electrification, such as providing a source of power that is independent of the availability of one type of fuel and reducing the air, noise, and vibration pollution, will be sufficient, on balance, to carry this project forward.

The basic electrification program is also contingent on other designated subsystem improvements. Curve realignments are necessary to achieve the maximum speeds, which in turn are dictated by the travel-time goals. Increased superelevation, spiral-length increase, and curvature-reduction requirements will cause shifts from a few centimeters to a meter or more to be made on selected curves.

Between New York and Washington, problems in the implementation of this program are particularly acute because of the proximity of the existing catenary poles to the track. Staged construction for this type of structure relocation is of prime importance in the current design and scheduling process. The information above on cost factors noted the significance of the impact of electrification on the signal systems. This is not of major design concern between New Haven and Boston because the age and condition of the existing signal system make it only sensible to replace the entire subsystem with new centralized traffic control facilities. The new track circuits will be designed to be compatible with the electrification system and can be independently installed while the existing system continues to function. Between New York and Washington, however, almost all track circuits will require modifications of the necessary hardware for compatibility with 25-kV 60-Hz propulsion. This represents a major cost and, more importantly, a very complex installation process.

Forty-nine overhead bridges, most of them between New Haven and Boston, require increased overhead clearance. Several of these, for example, those near South Station in downtown Boston, cannot be raised and may therefore cause a stretch of track to be lowered by as much as 0.6 m (2 ft). Several others may be adjusted in conjunction with the track undercutting program. The New York tunnels will require approximately 50 mm (2 in) of additional air-gap clearance for the installation of 25-kV lines. At this point in the engineering investigation, it appears that this may be achieved through lowering the track while implementing the necessary track rehabilitation program in the tunnels.

The electrification program also creates additional requirements for support facilities. The equipment-servicing facilities must be designed to have electrified storage and running tracks that will be sufficient to accommodate the split of equipment now planned to handle 1981 service (75 percent locomotive-hauled trains and 25 percent self-propelled multiple units). Plans for the facilities and equipment to service and maintain such a fleet at Boston and Washington will soon be placed for final design.

Maintenance-of-way base track layouts and buildings are also being designed to accommodate the equipment and crews for substation and catenary inspections and repair. Performance specifications are now being developed for new, specially designed catenary maintenance and inspection vehicles. An important part of these efforts in the design process is the analyses of constructibility and the ordering of the phases of construction, especially in regard to the track use requirements. Although there is no doubt that both passenger and freight service will be severely degraded by the construction program from now through 1981, there must be practical limits on the location, frequency, and duration of the interruptions of service.

Attaining the project objectives is dependent on the efficient planning of the various stages of construction. All subsystem construction needs must be identified and then combined to the maximum extent possible. The installation of the new system between New Haven and Boston will be the least complex portion of the program, both because it is being built from scratch and because the freight and commuter service schedules are minimal, which allows the tracks to be taken out of service for longer intervals.

The portion from New York to Washington, with its dense commuter and freight operations, presents more of a problem for hardware rehabilitation, retensioning, and reprofiling of the catenary, since these operations require that the track be occupied by the service trains. In addition, it will be necessary to interrupt the power to provide for construction around power-supply areas, and this will require careful coordination. With these factors uppermost in mind, the construction phasing and scheduling group has examined each construction procedure for the possibility of off-track implementation.

Several overseas electrification construction programs have been able to use specialized on-track equipment to bore the foundation holes, pour the concrete, and erect the catenary poles. On this project, many of those operations will have to use off-track equipment and methods wherever possible. Such operations as erection of a cantilever assembly, headspan construction, stringing or clipping in the wire, and alignment adjustment require the use of the track, and it must be reserved for these operations. Basic construction scheduling is being approached at this point on the basis of these steps:

1. Establish the priorities for projects on the basis of trip-time enhancement in each of several operating segments.
2. Identify site-specific project elements that permit no alternatives to preemption of the track.
3. Establish durations of track preemption on the basis of unit productivity.
4. Schedule those interruptions of service so that the track is available for the maximum time possible.
5. Analyze these results and adjust the construction stages and procedures accordingly.
6. Repeat the process until all project elements are established within program goals.

To aid this effort over the shorter term, the Track-Access Simulator will be used. This consists, in essence, of using stochastic computerized simulation to test the construction schedule by quantifying the maximum extent of each train's schedule-time degradation, while also identifying other windows in track use that would be available for such things as logistical support of ongoing projects or routine on-track maintenance, such as correction of track geometry and catenary inspection.

Last but not least, phase-in and cut-over plans will have to be developed for the electrification program as it is constructed and becomes operational. It is certainly recognized that the conversion of existing rolling stock and delivery schedules for new equipment will play a large role in these future scheduling plans.

The Railroad Revitalization and Regulatory Reform Act set travel-time goals of 2 h 40 min between New York and Washington and 3 h 40 min between New York and Boston. Electrification plays a major role in reaching those objectives. The same act stipulates that these goals be met by February 1981 at a maximum cost of $1.9 billion. The plans for those working on the project are to have history record that the goals were achieved.

Comment

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

The cost for the eventual future conversion from 11 kV 25 Hz to 12.5 or 25 kV 60 Hz is based on the market projections of future traffic demands. The figures mentioned were based on 14-car trains every 15 min in both directions. In spite of the fact that the National Passenger Railroad Corporation (Amtrak) has recently been involved in efficient promotional activities, the statistics indicate that the 4 to 6-car Metroliners, operating at 60-min intervals along with the longer and slower trains, are not more than about 50 to 75 percent filled normally. A professional market follow-up is recommended.

As a general comment to the plans of converting the catenary system, I would like to mention that in Europe 32 000 km (20 000 miles) are electrified with 15-kV 16.66-Hz current, and there are no known plans to change this system. Projection of an eventual electrification of the U.S. railroads indicates that 13 000 to 16 000 km (8000 to 10 000 miles) is the most probable length. The track length already now electrified with 11-kV 25-Hz current in the Northeast Corridor is about 2400 km (1500 miles) and, if an increase in power is eventually necessary, it could, based on European experience, be made at a lower cost by supplying some extra inverter stations of a type now available that is based on solid-state technology. We generally have difficulty in understanding the need for 3000-MW power for the future Northeast Corridor network. By comparison, the total power installed in the Swedish State Railways network, which has an electrified track length of 11 000 km (7000 miles), is 285 MW, in spite of the fact that this network is very spread out—a total north-south distance of 2400 km (1500 miles).

To make an electrified railroad competitive with other means of transportation in the future, every effort has to be made to optimize the system approach and not to overbuild the installation so that the system can never be competitive.

Author's Reply

The reference to 14-car trains every 15 min relates, of course, only to the peak-hour service, and any comparisons must relate to existing peak-hour services.

A major benefit of the Northeast Corridor Improvement Project will be the extension of high-speed status to all intercity passenger trains, which is expected to generate a considerable increase in passenger travel in major corridor segments. The increase in capacity of the power supply in the Northeast Corridor is just an incidental part of the main task of replacing all the existing 25-Hz installations in order to achieve the reliability objectives of the Railroad Revitalization and Regulatory Reform Act. The overall cost for a replacement 25-Hz system is much greater than the cost for a new 60-Hz system. Conversion of the European networks operating at 15 kV 16.66 Hz is not likely to be considered as long as the fixed installations continue to be operationally satisfactory without excessive maintenance cost.

The prospective increase in capacity of the electrified power-supply system for all routes south of New York is from the existing 240 MW available to about 325 MW in 1981 and to about 465 MW in 1990. This is comparable to the 320 MW that were available in 1970 before the recent failures and retirements of obsolete generating equipment. This larger capacity is required by the increase in train-kilometers and by the considerable increase in power demand caused by high acceleration rates and cruising speeds and by an increase in heating and air-conditioning loads. Some increase of capacity will be required between New York and New Haven, and new power-supply installations are required for the extension of electrification from New Haven to Boston, but the total capacity would be less than 700 MW rather than the 3000 MW suggested by Olson.

The Swedish State Railways, which travel fewer annual train-kilometers and have lower train densities, acceleration rates, and cruising speeds than the proposed eastern U.S. electrified network, would naturally require a lower power-supply capacity. Present work on redesigning the Northeast Corridor electrification systems is being undertaken on the basis of optimized system design that is consistent with cost-effective selection of electrical equipment. Funding constraints do not provide any opportunity for constructing excess capacity beyond the levels essential for normal and emergency-feed requirements on this high-density line, which includes several commuter-train networks and substantial freight-train operations.