FUTURE MOTIVE POWER
IN ELECTRIFIED TERRITORY

GENERAL ELECTRIC
Authority

At an exploratory meeting with the Director of Research of the Pennsylvania Railroad in Philadelphia on June 20, 1958 representatives of the General Electric were handed a file memorandum dated April 9, 1958 (Revised June 17, 1958) which outlined the objectives of a proposed study of the electrification. The Pennsylvania Railroad wanted the interested manufacturers to make independent reports which the Director of Research would use as a basis for making recommendations to the management of the Pennsylvania Railroad. A transcript of this memorandum is included as Appendix A. The principal subjects to be studied were:

1. Should the electrification be abandoned and electric motive power outside the New York tunnel area be replaced with diesel-electric motive power, using diesel-third rail locomotives to handle passenger trains in and out of New York. How would the commuter traffic be handled in this case?

2. If the electrification was to be continued should the present 11 KV 25 cycle single phase system be continued or should it be converted to single phase 60 cycles with the same or higher trolley-rail voltage?

3. The establishment of the goals for future motive power in the present electrified territory.

Conclusions

In 1955 General Electric cooperated with the Pennsylvania Railroad in assisting Gibbs and Hill Inc., Consulting Engineers, New York in an engineering and economic study of motive power replacement and evaluation of the electrification. The data contained in the report dated October 14, 1955 has been re-examined in the light of more recent traffic data (May 3-4-5, 1956 and May 7, 1959 records of freight trains dispatched on the electrified divisions) and the latest developments in motive power. On the basis of these and previous studies of the electrification General Electric recommends that:

1. The 132/12 KV 25 cycle single phase electrification should be continued. Extension of the electrification at the present time is not recommended at either 12 KV 25 cycles or commercial frequency.
2. When the combined effects of high maintenance cost and high fuel cost of high horsepower internally powered locomotives makes an extension of the electrification economically desirable, the whole question of voltage and frequency of the power supply should be examined in the light of developments in electric power generation, available sources of electric power, power requirements of the electrification, and the cost of conversion to single phase 25 cycles.

3. Possible extension of the electrification westward in the future at commercial frequency and conversion of the present system to commercial frequency should be considered in designing new motive power where this consideration does not increase the first cost and/or the operating cost of the equipment.

4. The rectifier type locomotive using the same type of traction motors and running gear as are used on diesel-electric locomotives be used to replace existing a-c locomotives in order to obtain the advantage of standard components wherever practical.

5. The a-c commutator type motor which has proved highly successful on MP54E6 cars be used for modernization of the multiple unit car fleet. Rectifiers can easily be added at a later date if it becomes necessary to operate the cars on 60 cycle trolleys.

6. The ninety P5, P5A and P5B locomotives be replaced immediately with sixty-six 70 mile per hour 4400 HP rectifier type locomotive units having a continuous tractive effort rating of 55,500 lb. at 21.5 MPH and 30,000 lb. at 55 MPH.

7. The forty-eight GG-1, one DD-2, six E-2B, two E-2C and two E-3B locomotive units that are used exclusively for freight service be replaced with twenty-seven 4400 HP locomotives (dupicates of those that replace the P5, P5A and P5B) and thirty units equipped with boilers for normal use in freight service, and occasional use in passenger service.

8. The remainder of the GG-1 locomotives be replaced with eighty-two 120 mile per hour 4400 HP locomotive units. These will have the same electrical equipment and auxiliaries as the freight units but the overall length will be increased to accommodate the train heating equipment. The trucks must be suitable for high speed passenger service.
9. MP54E1, MP54E2 and MP54E3 multiple unit cars be replaced with modern lightweight cars using Pioneer III type bodies (such as built by Budd) mounted on high speed trucks that will accommodate GEA-630 traction motors. These cars will be for commuter service. Consideration should also be given to using these cars for main line infrequent stop service between Washington, Philadelphia and New York.
HISTORY

According to an old Pennsylvania Railroad report the main line between New York and Washington was electrified because "studies indicated that probably by 1950 the metropolitan area around New York would extend to New Brunswick on the west and out on Long Island on the east and that there would be similar development in around Philadelphia and Baltimore. The railroad had electric operation in the terminals of New York and Philadelphia and it was desirable to have electric operation through the Baltimore tunnels. Because of the dense traffic in this territory, higher speeds, greater reliability and increased track capacity became desirable. More efficient operation under these conditions was possible with the use of electric power." Significant dates in 11 KV 25 cycle electrification history are:

M-U Service

<table>
<thead>
<tr>
<th>Year</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>1915</td>
<td>Philadelphia to Paoli</td>
</tr>
<tr>
<td>1918</td>
<td>Philadelphia to Chestnut Hill</td>
</tr>
<tr>
<td>1924</td>
<td>Philadelphia to White Marsh</td>
</tr>
<tr>
<td>1928</td>
<td>Philadelphia to Wilmington and to Westchester</td>
</tr>
<tr>
<td>1930</td>
<td>Philadelphia to Trenton and to Norristown</td>
</tr>
<tr>
<td>1932</td>
<td>New York to New Brunswick</td>
</tr>
<tr>
<td>1935</td>
<td>New York to South Amboy</td>
</tr>
</tbody>
</table>

Through Passenger Service

<table>
<thead>
<tr>
<th>Year</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>1933</td>
<td>New York - Philadelphia - Wilmington - Paoli</td>
</tr>
<tr>
<td>1935</td>
<td>New York to Washington</td>
</tr>
<tr>
<td>1938</td>
<td>New York - Philadelphia - Harrisburg</td>
</tr>
</tbody>
</table>

Electric freight operation was inaugurated in 1935. The P5A locomotives were originally designed and used in passenger service with 90 MPH gearing. These were converted to 70 MPH gearing when freight service between the Jersey Terminals and Potomac Yard was inaugurated. GG-1 locomotives were also designed for passenger service. The units that were geared for 90 MPH were used in freight service after test operations in 1938. Thus virtually all of the electric locomotives now in service on the Pennsylvania Railroad electrification were designed for passenger operation.

The MP54E1, E2 and E3 cars were all designed for maximum road speed of 65 to 70 miles per hour operation with one mile between stops. The MP54E5 and MP54E6 cars equipped after World War II were designed for a maximum speed of 90 miles per hour while at the same time being able to multiple with the older cars. The older cars are not suitable for through passenger service. This is particularly true of the E1 and E2 cars which use the now obsolete doubly fed motor which requires that power may not be reapplied at speeds in excess of 30 miles per hour if it has to be shut off for any reason. The maintenance cost of these old cars is excessive.
In 1956 General Electric made an economic study showing that the savings in maintenance would pay for the replacement of the P5A and GG-1 locomotives with modern rectifier units. At that time 5400 HP C-C rectifier type locomotives with a peak short time rating of 12,000 horsepower were proposed to replace the GG-1 locomotives in passenger service. The plan as recommended in the Gibbs and Hill report of October 14, 1955 was to buy new passenger units, transfer the GG-1 locomotives to freight operation and retire the P5A locomotives. The proposed locomotives had larger d-c motors than could be accommodated on 40 inch wheels. The continued decline in the prospects of passenger traffic and the rise in the cost of maintaining the GG-1 locomotives has made it unadvisable to follow the original plan. The excellent performance of the rectifier type locomotives that were put in service in 1956 on the Virginian Railroad, has shown that this type of locomotive is suitable for the Pennsylvania Railroad freight traffic on the electrified divisions. This is the type of locomotive unit that is recommended for replacement of P5A locomotives in freight service. The freight units should be replaced first. The basic design of the passenger units that is contemplated at the present time uses the same electrical equipment as the freight units. High speed trucks will be used. Should there be a further severe decline in passenger service these may be converted to freight operation by changing the gearing. This is a consideration on the selection of motive power for trains of extremely light weight coaches that have been proposed.
In recent years consideration has been given to the possible advantages of electrification at commercial frequencies. The majority of new electrifications in Europe and other foreign countries that have been undertaken since 1950 have been at single phase commercial frequencies. The conversion of the existing power supply from 12 KV 25 cycles to 12 KV 60 cycles could be made with only a minimum of changes in the substations. The 25 cycle power system was designed for 10% voltage regulation at the pantographs of the locomotive with a train hauled by six GG-1 locomotives and the remainder of the system heavily loaded, so that there is some possibility that 12 KV 60 cycle single phase trolley could be used with the present substation spacing. This would not provide for growth. Calculating board studies would be necessary to evaluate the system operation at 12 KV 60 cycles but an approximation can be obtained from consideration of the trolley rail regulation alone. It may be shown (Fig. 1) that a trolley-rail circuit having an impedance of 0.2 + j3.5 ohms per mile on 25 cycles can transmit 190% of the power at 80% lagging powerfactor that the same length of circuit can transmit at the same voltage at 60 cycles. The average power factor which was assumed when the system was designed was 80% and this will probably remain the same when the old locomotives are replaced with rectifier locomotives. It is probable that a calculating board study would show that the trolley voltage would have to be raised for successful operation at 60 cycles with existing substation spacings and anticipated loads. Cost estimates were made for the following two possible methods of converting to commercial frequency operation. These estimates are of the "order of magnitude" variety:

(1) Operation at 12 KV 60 cycles

(2) Operation at 25 KV 60 cycles

The former method may permit continued use of much of the 12 KV substation equipment now in use in the electrified zone. The latter method requires extensive changeout of equipment to accommodate the higher voltage.

These estimates do not convey the approval of the General Electric Company to operate any equipment of its manufacture at ratings other than those originally assigned to it, nor do they intend to indicate what performance might be expected of equipment of other manufacture.

Basis for Estimates

It has been necessary to make certain assumptions and simplifications in preparing these estimates, and those of a general nature are listed here. Other assumptions are noted in the discussion of specific estimates to which they apply.
In accordance with discussion at the July 9, 1958 meeting at the PRR's offices, these estimates are intended to apply to a curtailed electric operation consisting of mainline services only between Newark, Washington and Harrisburg.

1. Transmission line

It has been assumed that the railroad will continue to own and operate its 132-KV and 44-KV transmission circuits. Three-phase transmission of power will be accomplished by consolidating two present single-phase circuits into one three-phase circuit with a neutral conductor.

Where only one single-phase circuit exists at present, the possibility of continued single-phase transmission may prove feasible when a detailed study is made.

2. Delivery of Power to Transmission Lines

It has been assumed that the railroad will purchase power at transmission line voltage at suitable points of delivery to these lines. For the present, it is assumed that existing transmission line electrical equipment and switching structures can be adapted to use in the 60-cycle transmission system. No allowance has been made in these estimates for changes in the transmission system, nor has the feasibility of operating transmission line equipment at 60 cycles been determined.

3. Phase Balance of Traction Load

Transmission of three-phase power along the railroad will permit rotation of phases along the contact system to balance the single-phase traction loads among the three phases of the power supply system.

Experience in Europe and recent studies in this country suggest that adequate phase balance will be obtained in this manner. However, it is anticipated that the effect of residual load unbalances on the systems of the power suppliers would have to receive detailed study before the conclusion could be reached that special provision for phase balancing would not be required. No allowance for possible phase balancing is included in these estimates.

4. Step-Down Transformer Capacity Required

The present aggregate capacity of step-down transformers is approximately 750,000 kva.
For 12 KV, 60 cycle operation it is planned to retain this entire capacity to minimize the impedance of the power source. This implies relocation of certain transformers, and the costs of relocation have not been estimated.

For 25 KV, 60 cycle operation it is arbitrarily assumed that 600,000 kva of transformer capacity are required, in recognition of curtailment of operation into New York and of suburban services in the Philadelphia area.

5. Trolley Breakers Required

For conservative estimating purposes, it is assumed that nearly all present trolley breaker positions will be retained. Actually, a net decrease in trolley breaker positions is to be expected, after making allowance for transfer of certain yard and terminal switching functions from Sunnyside and Penn Station to the Newark area.

6. Number of Tracks

The number of tracks to be electrified will have a significant effect upon the cost of conversion to 60-cycle operation, especially in the 25 KV case which requires a substantial expenditure for new trolley breaker equipment.

Should a comprehensive review of the economics of electrified zone operation reveal that the high performance of electric motive power, possible traffic control innovations, advanced track maintenance techniques, and other factors permit elimination of one or more tracks - then economies can be expected in the cost of converting fixed electrification plant to 60-cycle operation.

7. Power Supply for Auxiliary Services

It has been assumed that station service transformers and distribution equipment will operate at 60 cycles at present voltage levels. Small motors and certain other items may require replacement. No provision has been made for changes of this nature in these estimates.

Signal power supply equipment which operates from 25 cycle sources will require modification or replacement. No provision has been made in these estimates for such changes.

8. Installation Costs

Estimates of costs of installing new equipment, of relocating equipment, and of removing superseded equipment are considered beyond the scope of this report.
12-KV, 60-Cycle Equipment Estimates

The equipment estimate for conversion to 12 KV, 60-cycle operation is presented in Table I. The equipment estimate of approximately $5,000,000 shown in this tabulation must be considered a "volatile" figure because a number of factors which have not been evaluated may influence it appreciably. Reference has been made to some of these factors under the heading "Basis for Estimates".

In the 12 KV, 60-cycle system, transformer and contact system reactances will increase in the ratio of 60/25, as compared to reactance values at 25 cycles. Preliminary estimates indicate that this will result in lower voltage at the traction motors of rectifier locomotives than would be realized with rectifier locomotives operating at 25 cycles. Roughly speaking, the rectified voltage at d-c traction motors with 12-KV, 60-cycle operation might be 50 to 60% of what it would be with 12-KV, 25-cycle operation, under otherwise identical conditions.

Voltage regulation may be improved by providing trolley breaker stations midway between widely-spaced substations to tie the contact wires together. If this is necessary for operation at 12-KV, 60 cycles, an equipment expenditure of the order of $5,000,000 must be added for approximately 300 trolley circuit breakers and associated equipment. Cost of installing new equipment and converting to 60 cycles is not included in these estimates.

25-KV, 60-Cycle Equipment Estimates

Operation at 25-KV has been considered on two bases:

(a) Acquisition of new stepdown transformers, and

(b) Rewinding of existing stepdown transformers for 25-KV service.

Estimates for these approaches are presented in Tables II and III, respectively. The "new transformer" approach involves an equipment expenditure of approximately $30,000,000, and the "re-wound transformer" approach involves an expenditure of somewhat over $26,000,000.

Circuit breaker equipment is a major part of the equipment expense estimated for the 25 KV alternatives, and it should be pointed out that these estimates are based upon a conservative application of trolley breakers. Air-blast breakers rated 25-KV, 1200 amperes, 1500 mva, 80-150 KV BIL, in a factory-assembled outdoor lineup were used as the basis of these estimates.

Cost of installation will be at least $14,000,000.
Installed Cost

It is estimated that the cost of changing from 12 KV single-phase 25 cycles to 12 KV, 60 cycles would be at least 10 million dollars and in the neighborhood of 40 million dollars to convert the system to 25 KV, 60 cycles.

Conclusion

In addition to the high cost of converting the roadway installations for 60 cycle operation, a large conversion program would have to be undertaken since all existing 25 cycle locomotives and multiple unit cars would have to be replaced immediately. It is estimated that the annual power bill would be reduced by 1.6 million dollars by buying power at single-phase 60 cycles instead of at 25 cycles. This saving would be achieved by not having to make provision for new frequency changers when the old ones wear out. The cost and inconvenience of conversion to 60 cycles cannot be justified on the basis of this relatively small saving. The electrification should remain at 12 KV, 25 cycles.
TABLE I

CONVERSION TO 12 KV, 60 CYCLE OPERATION

STEP-DOWN SUBSTATION EQUIPMENT COSTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Convert 750,000 kva of 25-cycle transformers to 60-cycle operation (Note 1)</td>
<td>$ 200,000</td>
</tr>
<tr>
<td>2</td>
<td>Replace 263 JRA breakers with 1-phase, 2000-ampere magneblast breakers at approx. $16,000 per circuit including relaying (Note 2)</td>
<td>4,250,000</td>
</tr>
<tr>
<td>3</td>
<td>Modify trolley breaker control for approx. 500 breakers (Note 2)</td>
<td>500,000</td>
</tr>
</tbody>
</table>

EQUIPMENT ESTIMATE $ 4,950,000

Notes

1. The present transformers are assumed to be operable at their present ratings at 60-cycles, with minor modifications at a cost not to exceed the figure shown.

2. Preliminary review indicates the JRA breakers would require replacement, although this is not a firm conclusion due to lack of 60-cycle test data. Other GE breakers are assumed operable at 60 cycles. No provision is made for changes in breakers of other manufacture, as information concerning their 60-cycle operation was not available during the preparation of these estimates. This does not include the 300 circuit breakers that may be needed for trolley tie stations.

3. Pending detailed study of the short-circuit detection problem by the railroad, this has been arbitrarily assumed to cost $1000 per breaker as an average figure.

J.C.P.
8/11/58
TABLE II
CONVERSION TO 25 KV, 60 CYCLE OPERATION

STEP-DOWN SUBSTATION EQUIPMENT COSTS
(NEW TRANSFORMERS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600,000 kva of new 132-25 KV, 1-phase, 60-cycle, 4500 kva step-down transformers, generally similar in overload capability, impedance, etc., to those now in 25-cycle service on the PRR, at approx. $15/kva.</td>
<td>$9,000,000</td>
</tr>
<tr>
<td>2</td>
<td>25-KV air-blast trolley breakers and transformer breakers for 63 step-down and switching stations at $325,000 per station based on an average of 8 trolley breakers per station. Necessary relaying, instrument transformers and compressed air supply included.</td>
<td>20,000,000</td>
</tr>
<tr>
<td>3</td>
<td>25-KV lightning arresters for 504 feeder circuits.</td>
<td>150,000</td>
</tr>
<tr>
<td>4</td>
<td>34.5-KV, 1200 ampere, manually-operated disconnect switches, type FA, for 504 feeder circuits.</td>
<td>150,000</td>
</tr>
</tbody>
</table>

EQUIPMENT ESTIMATE $29,800,000

J.C.P.
8/11/58
TABLE III

CONVERSION TO 25 KV, 60 CYCLE OPERATION

STEP-DOWN SUBSTATION EQUIPMENT COSTS
(REWOUND TRANSFORMERS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600,000-kva of rewound 132-25-KV, 1-phase, 60-cycle, 4500-kva step-down transformers, generally similar in overload capability, impedance, etc., to transformers now in 25-cycle service on the PRR, at approx. $9/kva (Note 1)</td>
<td>$5,400,000</td>
</tr>
<tr>
<td>2</td>
<td>25-KV air-blast trolley breakers and transformer breakers for 63 step-down and switching stations at $325,000 per station based on an average of 8 trolley breakers per station. Necessary relaying, instrument transformers and compressed air supply included.</td>
<td>20,500,000</td>
</tr>
<tr>
<td>3</td>
<td>25-KV lightning arresters for 504 feeder circuits</td>
<td>150,000</td>
</tr>
<tr>
<td>4</td>
<td>34.5-KV, 1200 ampere, manually-operated disconnect switches, type FA, for 504 feeder circuits.</td>
<td>150,000</td>
</tr>
</tbody>
</table>

EQUIPMENT ESTIMATE $26,200,000

Note (1) Based upon replacement of both high-voltage and low-voltage windings in existing transformers.

J.C.P.
8/11/58
When the electrification was conceived, the movement of passengers on fast schedules was a primary consideration. The inroads of automobile and bus transportation moving on high-speed throughways have cut deeply into railroad passenger traffic. Likewise trucks have cut into the freight traffic, but for certain classes of freight traffic there is no adequate substitute for the railroad either now or in the course of development.

The gross ton miles of freight and the passenger car miles moved over the electrified lines East of Harrisburg have decreased significantly during the last decade. The passenger traffic density on all electrified lines except in the New York Terminal area has decreased by over 25% since the main line electrification program was started over thirty years ago, so that track capacity is no longer a problem. However the ability of the railroad to handle war time traffic must be considered before any reduction in trackage is made.

The New York - Philadelphia passenger traffic and the commuter traffic into New York and Philadelphia is much denser than similar traffic anywhere else in the United States. The movement of these people on fast, economical schedules is essential to the welfare of these two metropolitan areas. There is no better way to get from downtown New York to downtown Philadelphia than by the PRR. This service will probably increase in importance to these cities and economical means must be provided by some agency.

The movement of large volume, long haul freight and so called "piggy-back" service will continue to increase with the increase in Gross National Product. Over 60% of the revenue from freight on the Pennsylvania Railroad comes from traffic that must move at high schedule speeds in order to compete with other forms of transport.

In view of the above considerations the assumption has been made in studying the possibility of diesel-electric operation, that approximately the same power must be provided for trains as is now provided for electric operation.

One of the considerations that has made electric operation of the passenger traffic necessary on the New York Division has been the fact that diesel-electric locomotives can not be operated under load in the New York tunnels. It has been assumed that a third rail system would be installed in the New York tunnels and dual powered locomotives for certain portions of the passenger traffic. Consideration was also given to the possibility of the development of authorities to handle all commuter traffic into New York and Philadelphia. This assumption was made to simplify the analysis, because if the conversion to diesel-electric operation can not be justified with this simplifying assumption, it certainly cannot be justified if the assumption proves to be false.
At the present time there are 150 electric locomotive units in freight service and 98 units in passenger service. The freight units would have to be replaced with 377 diesel-electric units of which 120 would be dual powered so that they may be used in passenger service during peak loads. The passenger units would have to be replaced with 328 dual powered diesel-electric locomotive units. The 150 electric locomotives in freight service may be replaced with 123 - 4400 HP rectifier type electric locomotives, of which 30 should be equipped with boilers for passenger operation as required. The passenger units may be replaced with 82 - 4400 HP rectifier type units. The cost of replacing the old electrics with new electrics will be approximately 111 million dollars while diesel-electric replacement would cost approximately 181 million.

The following tabulation shows the estimated comparison of the cost of locomotive repairs for existing electric locomotives, proposed new electric locomotives and new diesel-electric locomotives:

<table>
<thead>
<tr>
<th></th>
<th>Existing Electric</th>
<th>Proposed New Electric</th>
<th>New Diesel-Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight</td>
<td>6,556</td>
<td>1,470</td>
<td>7,250</td>
</tr>
<tr>
<td>Passenger</td>
<td>5,219</td>
<td>1,230</td>
<td>7,426</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11,775</td>
<td>2,700</td>
<td>14,676</td>
</tr>
</tbody>
</table>

20 Year Average Locomotive Repair Cost

<table>
<thead>
<tr>
<th></th>
<th>Freight</th>
<th>Passenger</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9,050</td>
<td>6,050</td>
<td>15,100</td>
</tr>
<tr>
<td></td>
<td>2,580</td>
<td>2,160</td>
<td>4,740</td>
</tr>
<tr>
<td></td>
<td>12,710</td>
<td>13,010</td>
<td>25,720</td>
</tr>
</tbody>
</table>

The Pennsylvania Railroad would therefore save an average of approximately 21 million dollars per year in locomotive maintenance for the next 20 years by purchasing new electric locomotives rather than diesel-electric locomotives. The old electric locomotives should be replaced with new units as rapidly as possible to take advantage of the large reduction in electric locomotive maintenance cost that will result.
ELECTRIC FREIGHT LOCOMOTIVE REPLACEMENT

One of the handicaps of the GG-1 and P5A locomotives has been their use of a-c traction motors that are not used anywhere else. The principal advantage of motor generator type locomotive and the rectifier type locomotive for alternating current systems is that they permit the use of the same d-c traction motors that are used on diesel-electric locomotives. Motor generator locomotives for 25 cycle systems must use 750 rpm motors for the main conversion set because single phase 2 pole motors can not be built economically. On the other hand, igniton tube rectifiers that have a continuous ampere rating required by the traction motors can deliver more power than the motors can absorb. The motor generator locomotive operates at unity or leading power factor whereas the rectifier locomotive operates at 80 to 85% power factor. This is not a handicap on a "stiff" power supply system such as the PRR 132/12 KV, 25 cycle system. For these reasons the rectifier locomotive is recommended for replacement of P5A and GG-1 locomotives. The basic locomotive unit that is recommended is of the type that has been in successful operation on the Virginian Railroad for three years. The advantage of having tried and proven units as prototypes is perhaps the most important argument for the selection of the rectifier type for replacement of the P5A and GG-1 locomotives.

The lowest maintenance cost for a fleet of locomotives is achieved when the fewest number of units are used. It is therefore desirable to get as much horsepower as possible into a single unit where horsepower is a primary consideration. This advantage must be balanced against the requirements of the variations between the traffic in one direction and the other. The four axle unit has proved to be the most versatile building block in the great majority of applications. In the case of an electric locomotive the weight of the transformer varies approximately as the square root of the kilovolt amperes and virtually the same control is required for a four axle locomotive as a six axle locomotive. Where weight per axle is limited to 60,000 to 65,000 lbs. per axle it is expensive to build a high horsepower rectifier type locomotive using only four GE-752 motors. A six axle (C-C) locomotive unit is therefore recommended.

A d-c traction motor such as the GE-752 motor is limited to a certain maximum voltage. This is a limit due to the strength of insulation under operating conditions on a locomotive and permissible voltage between commutator bars. On a rectifier locomotive this limit is lower than on a d-c generator because of the distortion of the traction motor current. As the speed of a d-c series motor increases on constant voltage the horsepower output decreases because of the proportionate increase in the counter electromotive force. As the speed decreases on constant voltage the horsepower output may be increased until the ability of the motor to commutate places a limit on further increase in horsepower output. As the speed decreases further with relatively constant horsepower output, the current taken by the traction motors increases until a limit is imposed by the heating of the armature and the horsepower output must be decreased to keep within acceptable limits. Finally a point is reached
where the heating of the field becomes limiting and no further increase in current can be permitted except for short periods of time. The continuous horsepower output of a d-c traction motor versus speed is therefore essentially trapezoidal in shape. Because of the constant horsepower output over a wide range in their speed, diesel-electric locomotives can not use all of the capacity of the traction motors economically. An electric locomotive does not have this limitation. The GE-752 motor has its maximum permissible output for freight operation between 40% and 68% of maximum speed. If the locomotive is geared to make maximum utilization of the adhesive weight the maximum permissible speed of the traction motors would correspond to a locomotive speed of 65 mph. This locomotive would not be suitable for operation of freight at high speed on the New York Division. It was therefore necessary to arrive at a compromise gear ratio.

The northbound freight traffic on the New York Division has moderate grades against it for a good portion of the way. A minimum requirement is that the motive power should be able to move trains at 50 miles per hour on the level. This means 8 lbs. per ton of train, assuming Davis friction. The limitations of the Morrisville to Potomac Yard profile makes the Enola-Waverly trains the heaviest northbound trains on the New York Division. The ruling Smithville grade requires 10 lbs. per ton at 30 miles per hour. The maximum horsepower is therefore required on the New York Division for 40 to 50 mile operation of trains. The following tabulation will show that high adhesion operation is not required on the Smithville grade. A 60,000 lbs. axle loading will be assumed. All horsepowers are at the rail.

<table>
<thead>
<tr>
<th>Percent Adhesion</th>
<th>Tons of Train</th>
<th>HP Per Axle at 30 MPH on Smith Grade</th>
<th>HP Per Axle at 45 MPH on Level</th>
<th>HP Per Axle at 50 MPH on Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
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This shows that a C-C locomotive that rates 4600 HP at 50 miles per hour will not have to operate at more than 12% adhesion over the Smithville grade if the tonnage is selected so that the train will be able to run at 50 MPH on the level.

A 4400 HP C-C rectifier type locomotive with 6 GE-752 motors with 63/20 gear ratio is recommended. The continuous tractive effort will be 55,500 lbs. which results in 15.4% adhesion with 60,000 lbs. per axle. Trains that require 55,500 lbs. tractive effort on the Smithville grade can not run at 45 miles per hour on
the New York Division except on down grades. The curve (41H135174) shows how the capacity of the motors has been related to road speed to obtain optimum results. The corresponding speed tractive effort curve is shown in (41H135173).

Dynamic braking is recommended to secure reduction in wheel wear and brake shoe maintenance. The braking resistors are used for acceleration between transformer taps but continuous operation is provided while on resistance notches. The Dynamic braking characteristic is shown in (41H115015).
HORSEPOWER-SPEED CURVE
FOR RECTIFIER-TYPE ELECTRIC LOCOMOTIVE

EQUIPMENT:
6-GE-752 MOTORS
63/20 GEAR RATIO
40" WHEEL DIAMETER

BASED ON 11 KV, 25 CYCLE,
SINGLE PHASE SUPPLY

HORSEPOWER AT RAIL

5000 6000

4000 3000

2000 1000

0 10 20 30 40 50 60 70

SPEED (KMPH)
TRACTIVE EFFORT-SPEED-CURRENT CURVES
FOR RECTIFIER-TYPE ELECTRIC LOCOMOTIVES

EQUIPMENT:
6 - GE-752 MOTORS
65/20 GEAR RATIO
40" WHEEL DIAMETER
BASED ON 11 KV, 25 CYCLE, SINGLE PHASE POWER SUPPLY.
SPEED-BRAKING EFFORT CURVE
FOR
11000 VOLT 25 CYCLE RECTIFIER TYPE
ELECTRIC LOCOMOTIVE FOR
PENNSYLVANIA RAILROAD
C-C 390/390 6-GE 752 MOTORS
GR 83/20 - WD 40"
(REFER H-8888267)
ELECTRIC PASSENGER LOCOMOTIVE REPLACEMENT

These locomotives should use the same electric traction equipment as the freight locomotives in so far as is practical.

The maximum authorized speed on the New York to Washington electrification is 80 miles per hour. The GG-1 locomotives that handle the passenger trains are geared for a maximum speed of 100 miles per hour and can deliver 7200 HP for short periods at 80 miles per hour. This is enough power to take a 15 car train of 70 ton cars at 80 miles per hour up a 0.65% grade without slackening speed. Grades of this order of magnitude on the New York to Washington lines can be taken on momentum without appreciably affecting the schedule speed. High horsepower is required between 45 miles per hour and 80 miles per hour to get back up to speed after a slowdown for a speed restriction or crossover. Accordingly the GG-1 locomotives deliver a peak of 8500 HP at 63 miles per hour.

The trend is towards using lightweight passenger cars similar to the Pioneer designs built by the Budd Company and weighing approximately 55 tons per car fully loaded. A train of 20 of these cars hauled by a locomotive weighing 180 tons will require 4000 HP at 90 miles per hour on the level. In anticipation of an increase in the authorized speed to 90 miles per hour it is suggested that a 56/27 gear ratio be selected so that 4000 HP can be obtained continuously at 90 miles per hour. With this gear ratio the locomotives will have a continuous rating of 4400 HP between 53 and 83 MPH.

In the discussion of the freight locomotive it was stated that in the middle speed range of the traction motor the horsepower output was limited by commutation. In passenger service operation at horsepowers above the continuous rating in this range of speed can be permitted for short periods. The curve (41H135329) is approximately the same as the short time horsepower output of the New Haven 4000 HP rectifier locomotives except that the gear ratio has been selected to get maximum short time horsepower output at approximately the same speed (60 miles per hour) as that at which maximum short time output is obtained from the GG-1 locomotives in passenger service.

A certain number of the passenger locomotives should have lower speed gearing to make them suitable for freight service during most of the year. These will be used for peak passenger loads. The gear ratio will be selected for optimum use of these units.
APPONIMATE APPLICATION LIMITS OF RECTIFIER-TYPE ELECTRIC LOCOMOTIVE FOR PASSENGER SERVICE.

Equipment:
6 - GE 752 Motors
56-27 Gear Ratio
40" Wheel Diameter

Based on 11 KV, 25 Cycle Single Phase Supply.
REPLACEMENT OF MULTIPLE UNIT CARS

Suburban train service is an essential part of the Pennsylvania Railroad from the standpoint of the people who use it everyday. The relationship of operating cost to revenue from this service is however not attractive. One reason for this situation is the high cost of maintaining the MP54E1, -E2 and -E3 cars. Many of these car equipments are over 40 years and none of the group are less than 25 years old. The equipments are mounted on obsolete passenger car bodies which have long past the end of their economic life. The situation in regard to the MP54E1 and MP54E2 cars is especially acute. The motors are an obsolete design whose limitations in regard to reapplication of power make them unsuitable for present day operations even in local service.

General Electric recommends that the MP54E1, -E2 and -E3 be replaced with new cars equipped with modern alternating current traction motors and control. It is suggested that lightweight bodies similar to the Budd Pioneer III cars be used but that these be mounted on lightweight trucks capable of accommodating the GEA-630 motor. The equipment on the MP54E6 cars consisting of GEA-630 traction motors with a cam operated resistance type control operating from an askarel type transformer has been very successful. This type equipment is recommended for the new lightweight cars.

Another cause of high operating cost has been the low mileage that can be obtained in purely commuter service. This situation has been improved by operating these cars on intercity service with frequent stops. A further increase in mileage can be obtained by making use of the unused capacity in the GEA-630 motor and gear them for balancing speeds between 100 to 110 MPH for use in high speed trains making infrequent stops between New York and Washington. Performance calculations have shown that trains of the proposed lightweight cars consisting of 4 motor cars and 2 unmotorized trailers or 7 motor cars and 5 trailers can maintain a 3 hour schedule between New York and Washington with five intermediate stops and be within the capacity of the GEA-630 motors provided that the speed limits are raised to take advantage of the higher balancing speed. (41H155021) shows the proposed speed tractive effort curve for use during acceleration.

The GEA-630 motor will operate successfully on rectified single phase 60 cycles so that the equipment may be used on a 12 KV, 60 cycle trolley simply by inserting a rectifier to provide "undulating" current to the GEA-630 motors.

D.R. MacLeod
General Electric Company
Erie, Pennsylvania
October 8, 1959
CAR CHARACTERISTIC
4-GE-630 MOTORS-2S-2P
120/36 G.R.-36" WHEELS

AMPS PER MOTOR

TRAIN RES. 7M-5T

600 V.

440 V. TAP

275 V. TAP

275 V. & .099 REL

0
100
200
300
400
500
600
700
800
900
100
110
120

M.P.H.

0
1000
2000
3000
4000
5000
6000
7000

TE.-4 MOTORS
APPENDIX A

Philadelphia, Pa., April 9, 1958
(Revised June 17, 1958)

Subject: Future Motive Power Requirements in Electrified Territory

MEMORANDUM FOR THE FILE:

A. This was discussed at a conference the morning of April 8 in the office of the Vice President, Operations. Present were:

Milton La Riviere, Manager, Eastern Region, Electro-Motive Division, General Motors Corporation.

M.C. (Pete) Warren, Eastern District Sales Manager, Electro-Motive Division, General Motors Corporation.

(Office of both 230 Park Avenue, New York 17, New York, telephone Murryhill 6-2315)

J.P. Newell, Vice President, Operations, PRR
J.J. Clutz, Director of Research, PRR

B. In the electrified territory, the PRR is faced with two things:

1. Most of our power is now purchased from the Philadelphia Electric Company. The contract runs out soon. Philadelphia Electric is requesting substantial increases, in both demand and special facilities charges, for a new contract. Our other power contracts also expire within the next few years. Undoubtedly, we will be faced with similar rate increases.

2. Our present electric locomotives and multiple unit cars are largely obsolescent. Maintenance costs are becoming very high.

C. Several more or less unrelated studies have been, or are being made, in connection with various phases of this over-all picture:

1. Some three years ago a joint study was prepared by Gibbs and Hill, General Electric Company and PRR on motive power replacement with evaluation of electrification. This included the possibilities of extension of the electrification.

2. Later, General Electric, on their own initiative, submitted a replacement program proposal for our passenger and freight electric locomotives and MU cars.
3. The Research and Development Department, through a committee under the chairmanship of Mr. J. W. Leonard, made a study, and report, about a year ago, on what might be done with our electric locomotives.

4. The same committee made a study, and report, on what might be done with regard to replacement of our multiple unit suburban commuter service fleet. As a result of this study, six prototype multiple unit cars, of a totally new design, have been ordered from The Budd Company, with Westinghouse electrical equipment, for test purposes. Delivery is scheduled for the summer of 1958.

5. The General Motors Company, Electro-Motive Division, has developed the FL-9 diesel-electric-third rail locomotive for the New Haven. A number of them are now in satisfactory service. They have been tested by the Pennsylvania, for the New York and Long Branch commuter service in and out of Pennsylvania Station, New York.

6. The New Haven also has prototype test trains, for diesel-third rail service in and out of Grand Central Terminal, in the New York - Boston service, involving:
   a. Modified Budd RDC cars.
   b. Baldwin-Lima-Hamilton mechynro locomotive units on both ends of especially designed cars made by Pullman-Standard.
   c. Fairbanks Morse opposed piston diesel locomotive units on both ends of especially designed cars made by ACF.

(Note: The modified Budd cars are now operating entirely outside of third-rail territory and the other two trains have been stored.)

7. An active study of what can be done about the Philadelphia Electric Power contract is under way, under the chairmanship of the Vice President, Special Services, assisted by representatives of the Vice President, Transportation & Maintenance, and the Research Department.

8. Our diesel locomotive fleet is now reaching the point, in age, where accurate figures on maintenance cost, and trends, should be available. However, detailed cost records go back only to 1953, since when a great deal of maintenance work has been deferred. As a result of these facts, trends based on available records are of doubtful value.
D. To tie all these together, and to provide a basis for a policy decision, it is desired the Research Department initiate a study to determine the future of electrified service on the Pennsylvania Railroad. Among the points which should be included are:

1. Electrification now involved is 11,000 volt 25 cycle AC current - excepting for 600 volt DC third rail also in service between Newark and Jersey City and in the Pennsylvania Station, New York, terminal area - including through both the east and north river tunnels. This involves special conversion equipment, in connection with main power supply, since practically all of commercial power today is 60 cycle. Developments in recent years have also made it possible to use 22,000 volt current in the catenary system, thus eliminating the need for the high tension transmission system, and most, if not all substations. Considerably cheaper catenary construction has also been developed in recent years.

   a. Should we continue with 25 cycle electrification, replacing the present equipment - or rebuilding it - as such, or

   b. Should we go to 60 cycle and if so should it be at 11,000 volts, 22,000 volts or 25,000 volts.

      If we go to 60 cycle, should the change be made "all at once", or could it be by sectionalized stages - to run out the mileage left in the locomotives and cars still serviceable?

2. Should we give up electrification, and use FL-9 type diesel-third rail locomotives to handle through passenger trains in and out of New York?

   a. What would that mean to our through passenger schedules? (It is understood studies have shown this might add as much as 25 minutes to the time between New York and Harrisburg.)

   b. How would we handle the commuter service? Should we retain an overhead catenary system in the Philadelphia suburban commuter service, and for the New York service, as far as New Brunswick and South Amboy, for example?

   c. Would it be feasible to adapt Budd RDC type equipment for the commuter service - using third rail power in and out of Suburban Station, Philadelphia, and Pennsylvania Station, New York, similar to that on the New Haven's RDC New York - Boston train?
3. What are present costs in connection with the catenary system - maintenance, taxes, prospective renewal, etc.

4. What are present, and prospective, costs in connection with the maintenance of our present electric locomotives and MU cars?

5. Obviously, the Philadelphia Electric Power contract as well as our other propulsion power contracts, including the proposed new cost under renewals, must be considered.

E. It is desired that the Director of Research handle this study, working with appropriate representatives of the Vice President, Transportation & Maintenance, and with the major manufacturers involved (General Motors, General Electric, and Westinghouse). General Motors wishes to help us on this study. They would probably be represented by their Kenneth Wolfe.

This study should, of course, be tied in with that on the Philadelphia Electric contract, now being headed up by Mr. Patchell.

F. The Pennsylvania has from six to twelve months before it needs to make a decision about purchasing of new equipment. We should know about the end of 1958 what operating results can be expected from new MU equipment, as exemplified by the six prototype Budd-Westinghouse cars to be delivered this summer.

G. The study should result in determination of goals for future motive power in the present electrified territory, and would be a guide for both the PRR and the affected manufacturers.

J. J. C.