Joint Electrification of
Steam & Electric Railways

Electrical Engineering

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JOINT ELECTRIFICATION OF STEAM AND ELECTRIC RAILWAYS

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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Joint Electrification of Steam and Electric Railways.

I. Introduction.

1. Preliminary.—The purpose of this investigation is to determine the feasibility of the joint electrification of all steam and electric railways of the United States. There are a great many indications that point in this direction and the question has been frequently touched upon by engineers of high standing, who are in a position to realize the trend of engineering development. It is the intention, however, to merely assemble the available data on this subject and to present unbiased results, and it is the desire to take the same attitude in the matter as that taken by Samuel Insull who, in a paper before the American Institute of Electrical Engineers in June 1912, said—"It is reasonable that I should assume that the electrification of steam railroads has come to stay, that the work done by the premier trunk lines centering in New York is a sufficient indication of what we may expect in the future. I am not in sympathy with an agitation to force the steam railroads in this country to electrify. That is a question of the provision of the capital necessary for the purpose, and that question must be taken up and settled by those who are responsible for the operation of the properties." It is along the lines of the last remark quoted that this paper deals, namely, to determine in a
preliminary manner whether there would be sufficient returns on the capital necessary to jointly electrify all railroads at the present time.

2. Advantages of Electrification.—Among the advantages for electrification of steam railroads, as outlined by Edward P. Burch in his book entitled—"Electric Traction for Railway Trains"—are the following:

1. Economy of operation on trunk lines. Saving in power, wages and maintenance.
2. Cheaper power from fuels and cheaper power from water power.
3. Capacity, draw-bar pull and speed for rapid transit and dense passenger service.
4. Economy and capacity on mountain grade railroads and in heavy freight haulage.
5. Smoke nuisance, exhaust noise and fire risk avoided.
6. Compulsory for safety and comfort at railroad terminals and yards.
7. Financial situation relieved; lost traffic regained; new business induced.
8. Demand for frequent and rapid suburban service and the necessity for increasing the carrying capacity and the speed of trains without excessive capital expenditure.

There is greater flexibility in the operation of electric railroads. Two electric locomotive units can be controlled from the cab by one operator, whereas with steam locomotives two engineers and two firemen are needed.

There is greater simplicity of moving parts in the electric locomotive as compared to the steam locomotive.

Greater reliability results from the simplicity of operation of electric trains.
There is better safety to life and property for the following reasons as stated by the same writer:-

1. The design of electric motors avoids track pounding.
2. Control circuits prevent accidents.
3. Automatic devices safeguard operation.
4. Speed may be decreased with safety, or limited by design.
5. Long wheel bases are avoided on trucks.
6. Vigorous tests are easily made.
7. Regeneration of energy in braking prevents accidents.
8. Tunnels are made safer.
9. Boilers are avoided.
10. Fire risk to property is decreased.
11. Exhaust steam and smoke are absent.
12. Engine men are not distracted from their duty.
13. Electric meters assist in operation.
14. Weights are not excessive so as to spread rails.

The financial advantages are:-

1. Gross earnings are increased.
2. Operating expenses are decreased.

3. Disadvantages to Electrification.-- The principal disadvantage to electrification is the danger to employes and the public from the use of electric power.

Another disadvantage which might be stated is the necessity in electrification of depending upon electric power plants for the entire motive power. This, however, can be obviated by the joint electrification of all railways and properly linking the generating
stations, and by duplication of transmission lines.

4. Advantages of Joint Electrification.—Among the advantages favoring joint electrification and operation of all railways are the following:

1. Avoidance of duplication of lines between given centers.
2. Ability to obtain the maximum service from any one connecting line.
3. Better safety to passenger traffic which could be obtained by concentrating efforts on the lines used.
4. The concentration of power and power sources.

The factors which favor a comprehensive transmission and distribution system for serving any large territory rather than disconnected central stations as summarized by Wm. B. Jackson in a paper before the American Institute of Electrical Engineers in February 1911, were stated as follows:

1. Saving in powerhouse equipment made possible through taking advantage of the diversity factor of the different communities by serving them from the same transmission system.
2. Lower power generating costs per kilowatt-hour due to larger power plants and improved load factor.
3. Less investment in power plants per kilowatt capacity on account of larger plants as compared with smaller.
4. The possibility of decreased percentage of spare apparatus by appropriate arrangement of power plants.
5. Saving in costs made possible by centralized management, general superintendence and other general expenses.
6. The possibility of providing rural and suburban service that could not be profitably reached by local central stations.
7. The possibility of large corporations providing power service which would be too extensive for small companies to undertake.
8. The development of water power for electric service.
II. ELECTRIC POWER REQUIRED TO OPERATE RAILWAYS.

5. Present Electric Railways, Jointly Electrified.—In determining upon the power required to operate the present electric railways of the United States, the best available information at hand is that contained in the McGraw Electric Railway Manual for 1911 which gives the statistics for electric railways for the fiscal year 1910.

In Table I, Columns a, b, c, d, e, f and g, are given the statistics compiled from this manual by groups of states. The grouping adopted is that used by the Interstate Commerce Commission in its reports entitled "Statistics of Railways in the United States"—which is approximately as follows:

Group 3. Ohio, Indiana, Michigan.
Group 4. West Virginia, Virginia, North Carolina, South Carolina.

Column h. Table I, gives the calculated operating expenses of all the electric railways in each group, assuming that the operating expenses of all the companies are proportional to the operating expenses of the reporting companies as
### TABLE 1.

Power Required By Electric Railways in the United States, Jointly Electrified.

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>No. of Ry. Co's.</td>
<td>Miles of Track</td>
<td>No. of Cars</td>
<td>Reporting Companies</td>
<td>No. of Ry. Co's.</td>
<td>Miles of Track</td>
<td>Operating Expenses</td>
<td>Calculated Total Operating Expenses for all Companies</td>
<td>Calculated Total Car Miles</td>
<td>Kilowatt-Hours Required Per Year</td>
</tr>
<tr>
<td>I</td>
<td>132</td>
<td>5 430</td>
<td>15 327</td>
<td>101</td>
<td>5 136</td>
<td>28 635 335</td>
<td>30 300 000</td>
<td>199 000 000</td>
<td>518 000 000</td>
<td>146 000</td>
</tr>
<tr>
<td>II</td>
<td>462</td>
<td>11 327</td>
<td>32 770</td>
<td>245</td>
<td>10 647</td>
<td>102 495 015</td>
<td>109 000 000</td>
<td>717 500 000</td>
<td>1 865 000 000</td>
<td>527 000</td>
</tr>
<tr>
<td>III</td>
<td>160</td>
<td>7 827</td>
<td>10 684</td>
<td>90</td>
<td>6 905</td>
<td>32 152 153</td>
<td>36 400 000</td>
<td>239 000 000</td>
<td>622 000 000</td>
<td>176 000</td>
</tr>
<tr>
<td>IV</td>
<td>58</td>
<td>1 061</td>
<td>1 826</td>
<td>18</td>
<td>553</td>
<td>3 863 738</td>
<td>7 420 000</td>
<td>43 800 000</td>
<td>113 800 000</td>
<td>32 300</td>
</tr>
<tr>
<td>V</td>
<td>69</td>
<td>1 818</td>
<td>3 668</td>
<td>29</td>
<td>1 497</td>
<td>11 637 571</td>
<td>14 140 000</td>
<td>93 000 000</td>
<td>243 800 000</td>
<td>68 300</td>
</tr>
<tr>
<td>VI</td>
<td>153</td>
<td>5 157</td>
<td>11 011</td>
<td>72</td>
<td>4 637</td>
<td>46 883 682</td>
<td>52 100 000</td>
<td>342 500 000</td>
<td>890 000 000</td>
<td>251 000</td>
</tr>
<tr>
<td>VII</td>
<td>17</td>
<td>392</td>
<td>737</td>
<td>5</td>
<td>268</td>
<td>2 360 000</td>
<td>3 450 000</td>
<td>22 860 000</td>
<td>59 400 000</td>
<td>16 800</td>
</tr>
<tr>
<td>VIII</td>
<td>81</td>
<td>2 146</td>
<td>4 170</td>
<td>24</td>
<td>1 540</td>
<td>15 840 953</td>
<td>22 100 000</td>
<td>145 200 000</td>
<td>377 000 000</td>
<td>106 500</td>
</tr>
<tr>
<td>IX</td>
<td>46</td>
<td>892</td>
<td>1 781</td>
<td>12</td>
<td>596</td>
<td>7 805 003</td>
<td>11 670 000</td>
<td>76 800 000</td>
<td>199 700 000</td>
<td>56 400</td>
</tr>
<tr>
<td>X</td>
<td>101</td>
<td>4 038</td>
<td>7 627</td>
<td>24</td>
<td>2 217</td>
<td>20 402 792</td>
<td>37 200 000</td>
<td>245 000 000</td>
<td>637 000 000</td>
<td>179 700</td>
</tr>
<tr>
<td>Total U.S.</td>
<td>1 279</td>
<td>40 088</td>
<td>89 601</td>
<td>620</td>
<td>33 996</td>
<td>272 076 243</td>
<td>323 780 000</td>
<td>2 124 660 000</td>
<td>5 525 700 000</td>
<td>1 560 000</td>
</tr>
</tbody>
</table>
the miles of track operated; values in Column h being equal to values in Column g times values in Column c divided by values in column f.

Column i gives the calculated car miles, being based on the assumption that the average operating expenses per car-mile is 15.2 cents, as indicated by a table given by Burch in his treatise before mentioned, on Page 48. This figure is also substantiated by innumerable other sources, but may be slightly low, making the number of car-miles slightly large.

Column j gives the kilowatt hours required per year based on 2.6 kilowatt-hours per car-mile, which figure was derived as follows:

\[
\text{Average weight of car} = 30 \text{ tons} \\
\text{Average power consumption per ton} = 70 \text{ watt-hours} \\
25\% \text{ additional power required in Winter} \\
\text{on account of cold and for heating cars} = 17.5 \text{ watt-hours} \\
\text{Total average power consumption per ton-mile} = 87.5 \text{ watt-hours} \\
\text{Total average power consumption per car-mile,} = 30 \times 87.5 = 2.6 \text{ kilowatt-hours} \\
\]

Column k gives the maximum demand at contacts, based on 40\% load factor.

6. Present Steam Railroads, Jointly Electrified.— On account of the nature of available information on steam railways, it was considered sufficient to assume that all tracks and lines would be electrified. There are, of course, some cases such as some logging roads where the traffic is not sufficient to warrant more than a single gasoline car, but the percentage of such roads, or other questionable roads, is so small that the ultimate conclusions of the investigation would not be seriously effected.

Taking the statistics contained in the previously mentioned Interstate Commerce Commission Report for the year 1910, Table II was compiled.

Columns a, b, c and d give the locomotive-miles and car-miles for the different types of cars and kinds of service.
## TABLE II.

Power Required by Steam Railroads in the United States, Jointly Electrified.

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kind of Service</strong></td>
<td><strong>Locomotive Miles Millions</strong></td>
<td><strong>Kind of Cars</strong></td>
<td><strong>Car Miles Millions</strong></td>
<td><strong>Est. Av. Tons Per Car</strong></td>
<td><strong>Ton-Miles Millions</strong></td>
<td><strong>Watt-Hours Per Ton Mile</strong></td>
<td><strong>Kilowatt-Hrs Per Year g x f x 1.25/1000</strong></td>
<td><strong>Load Factor</strong></td>
<td><strong>Maximum Demand h x 1,000,000/8760 x 1 Kilowatts</strong></td>
</tr>
<tr>
<td>Freight</td>
<td>722.8</td>
<td>------</td>
<td>----</td>
<td>90</td>
<td>65 000</td>
<td>70</td>
<td>5 680</td>
<td>.70</td>
<td>927 000</td>
</tr>
<tr>
<td>Freight</td>
<td>---</td>
<td>Empty Cars</td>
<td>5 498.3</td>
<td>20</td>
<td>110 000</td>
<td>30</td>
<td>4 125</td>
<td>.70</td>
<td>673 000</td>
</tr>
<tr>
<td>Freight</td>
<td>---</td>
<td>Loaded Cars</td>
<td>12 851.3</td>
<td>50</td>
<td>642 000</td>
<td>30</td>
<td>24 080</td>
<td>.70</td>
<td>3 930 000</td>
</tr>
<tr>
<td>Freight</td>
<td>---</td>
<td>Caboose</td>
<td>631.3</td>
<td>10</td>
<td>6 300</td>
<td>30</td>
<td>236</td>
<td>.70</td>
<td>38 500</td>
</tr>
<tr>
<td>Passenger</td>
<td>567.0</td>
<td>------</td>
<td>----</td>
<td>10</td>
<td>51 000</td>
<td>70</td>
<td>4 400</td>
<td>.40</td>
<td>1 258 000</td>
</tr>
<tr>
<td>Passenger</td>
<td>---</td>
<td>Coaches</td>
<td>1 420.4</td>
<td>35</td>
<td>49 700</td>
<td>40</td>
<td>2 484</td>
<td>.40</td>
<td>708 500</td>
</tr>
<tr>
<td>Passenger</td>
<td>---</td>
<td>Pullman</td>
<td>628.2</td>
<td>70</td>
<td>44 000</td>
<td>40</td>
<td>2 200</td>
<td>.40</td>
<td>628 000</td>
</tr>
<tr>
<td>Passenger</td>
<td>---</td>
<td>Other</td>
<td>949.6</td>
<td>50</td>
<td>47 500</td>
<td>40</td>
<td>2 350</td>
<td>.40</td>
<td>680 000</td>
</tr>
<tr>
<td>Mixed</td>
<td>37.0</td>
<td>Trains</td>
<td>----</td>
<td>500</td>
<td>18 500</td>
<td>40</td>
<td>925</td>
<td>.40</td>
<td>264 500</td>
</tr>
<tr>
<td>Special</td>
<td>1.8</td>
<td>Trains</td>
<td>----</td>
<td>90</td>
<td>162</td>
<td>70</td>
<td>14</td>
<td>.40</td>
<td>4 060</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Loaded Fr't.</td>
<td>6.1</td>
<td>50</td>
<td>305</td>
<td>30</td>
<td>11.4</td>
<td>.40</td>
<td>3 260</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Empty Fr't.</td>
<td>.1</td>
<td>20</td>
<td>2</td>
<td>30</td>
<td>0.1</td>
<td>.40</td>
<td>29</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Caboose</td>
<td>.4</td>
<td>10</td>
<td>4</td>
<td>30</td>
<td>.2</td>
<td>.40</td>
<td>57</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Pass.Coaches</td>
<td>3.4</td>
<td>35</td>
<td>119</td>
<td>40</td>
<td>5.9</td>
<td>.40</td>
<td>1 687</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Pullman</td>
<td>1.2</td>
<td>75</td>
<td>90</td>
<td>40</td>
<td>4.5</td>
<td>.40</td>
<td>1 288</td>
</tr>
<tr>
<td>Special</td>
<td>---</td>
<td>Other Pass.</td>
<td>1.3</td>
<td>50</td>
<td>65</td>
<td>40</td>
<td>3.2</td>
<td>.40</td>
<td>914</td>
</tr>
<tr>
<td>Switch</td>
<td>316.6</td>
<td>------</td>
<td>----</td>
<td>250</td>
<td>79 100</td>
<td>120</td>
<td>11 870</td>
<td>.75</td>
<td>1 807 000</td>
</tr>
<tr>
<td>Non-Rev.Sen.</td>
<td>69.2</td>
<td>Trains</td>
<td>----</td>
<td>400</td>
<td>27 700</td>
<td>32</td>
<td>1 108</td>
<td>.40</td>
<td>316 000</td>
</tr>
</tbody>
</table>

**Total** | **1 714.4** | **21 991.6** | **1 125 647** | **53** | **59 527.5** | **.62** | **10 925 795** |
Column e gives the assumed average weight per car as obtained from
the same and other sources.

Column f gives the ton-miles, being the product of Column e and
Column b in the case of locomotive ton-miles, and the
product of Column e and Column d in the case of car ton
miles.

Column g gives the assumed watt hours per ton mile for the different
kinds of service, as deduced from calculations made with
the aid of the treatise by Burch and compared with data
contained in the following and other sources:

American Institute of Electrical Engineers Transactions,
Volume 31, Page 1473. "The Relation of Central Station
Generation to Railway Electrification" - by Samuel Insull.

American Institute of Electrical Engineers Transactions,
Volume 31, Page 741. "Freight Train Tests on an Electric
Interurban Railway" - S.T. Dodd.

Column h gives the kilowatt hours per year, being the product of
Column f and Column g, increased by 25% to allow for extra
power required by trains in wintertime on account of cold
and for heating passenger cars.

Column i gives the assumed load factors for the different kinds of
service as deduced from the previously mentioned papers
and other sources.

Column j gives the maximum demand at the contacts based on the load
factor given in Column i, being equal to the total kilowatts
per year divided by (8760) the number of hours in a year,
and the load factor.

From this table we arrive at the conclusion that the total
kilowatt-hours at the contacts required per year by all the steam
railroads of the United States is 59 527 500 000 kilowatt-hours, and
the total maximum demand at the contacts is 10 925 795 kilowatts.

It is reasonable to assume that the proportional maximum demand
for any given railroad or group of railroads would be in proportion
to the number of locomotives in service. The total number of locomo-
tives in service in the United States during the year 1910 was
58 947, therefore the average maximum demand at contacts per locomo-
tive in service was \[ \frac{10 925 795}{58 947} \approx 185.4 \text{ kilowatts}. \] And the total
### TABLE III.

Total Power Required by Steam and Electric Railways, Jointly Electrified.

<table>
<thead>
<tr>
<th>Group</th>
<th>Locomotives in Service</th>
<th>Kilowatt-Hours per Year at Contacts</th>
<th>Maximum Demand at Contacts</th>
<th>Maximum Demand at Power Plant Thousands of Kw.</th>
<th>Normal Rating Power Plant Thousands of Kw.</th>
<th>Load Factor on Power Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>e</td>
<td>f</td>
<td>i</td>
</tr>
<tr>
<td>I</td>
<td>3 297</td>
<td>3 310</td>
<td>518</td>
<td>3.82</td>
<td>608</td>
<td>146.</td>
</tr>
<tr>
<td>II</td>
<td>13 607</td>
<td>13 670</td>
<td>1 865</td>
<td>15.53</td>
<td>2 512</td>
<td>527.</td>
</tr>
<tr>
<td>III</td>
<td>8 994</td>
<td>9 040</td>
<td>622</td>
<td>9.66</td>
<td>1 659</td>
<td>176.</td>
</tr>
<tr>
<td>IV</td>
<td>3 102</td>
<td>3 115</td>
<td>113.8</td>
<td>3.22</td>
<td>572</td>
<td>32.3</td>
</tr>
<tr>
<td>V</td>
<td>4 700</td>
<td>4 725</td>
<td>243.8</td>
<td>4.96</td>
<td>868</td>
<td>68.3</td>
</tr>
<tr>
<td>VI</td>
<td>10 707</td>
<td>10 770</td>
<td>890.0</td>
<td>11.66</td>
<td>1 976</td>
<td>251.</td>
</tr>
<tr>
<td>VII</td>
<td>2 480</td>
<td>2 492</td>
<td>59.4</td>
<td>2.55</td>
<td>458</td>
<td>16.8</td>
</tr>
<tr>
<td>VIII</td>
<td>5 971</td>
<td>6 000</td>
<td>377.0</td>
<td>6.37</td>
<td>1 102</td>
<td>106.5</td>
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<tr>
<td>IX</td>
<td>2 427</td>
<td>2 435</td>
<td>199.7</td>
<td>2.63</td>
<td>447</td>
<td>56.4</td>
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<tr>
<td>X</td>
<td>3 662</td>
<td>3 680</td>
<td>637.0</td>
<td>4.31</td>
<td>676</td>
<td>179.7</td>
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<tr>
<td>Total U.S.</td>
<td>58 947</td>
<td>59 237</td>
<td>5 525.7</td>
<td>64.76</td>
<td>10 878</td>
<td>1 560.0</td>
</tr>
</tbody>
</table>
average kilowatt hours per year per locomotive in service was
\[ \frac{59 \, 273 \, 500 \, 000}{58 \, 947} = 1 \, 004 \, 000 \text{ kilowatt hours.} \]

7. All Steam and Electric Railways Jointly Electrified.—

Table III was compiled to determine the total power required by the combined steam and electric railways of the United States.

Column a gives the group numbers.

Column b gives the locomotives in service during 1910 for each group.

Column c gives the total kilowatt-hours required by each group per year, being the product of Column b and 1 004 000, the average kilowatt hours required per year per locomotive in service.

Column d gives the kilowatt-hours required per year by the electric railways, by groups, as developed in Table I, Column j.

Column e gives the total kilowatt-hours required per year by both steam and electric railways, by groups, being the sum of Column c and Column d.

Column f gives the maximum demand at contacts for present steam railroads, by groups, being the product of Column b and 185.4 kilowatts, the maximum demand at contacts per locomotive in service.

Column g gives the maximum demand at contacts, by present electric railways, as obtained from Table I, Column k.

Column h gives the total maximum demand at contacts for the combined steam and electric railways, being the sum of Column f and Column g.

Column i gives the maximum demand at power generating stations assuming 70 per cent efficiency between generators and contacts.

Column j gives the normal rating of the generating equipment necessary based on an overload capacity for two hours of 25 per cent.

Column k gives the load factor on power plants in per cent.
III. POWER PLANTS.

8. Types.— In determining upon the types of power plants best adapted to the various localities, we have eight principal types to select from, as follows:—

1. Steam turbine-electric stations burning coal.
2. Hydro-electric stations.
4. Natural gas engine-electric stations.
5. Crude oil engine-electric stations.
7. Steam turbine-electric stations burning fuel oil.
8. Steam turbine-electric stations burning natural gas.

Type 1, Steam turbine-electric stations burning coal were found the most adaptable and economical, except in localities where good steam coal is expensive, or where water power is available in large quantities.

Type 2, Hydro-electric stations were used in all localities where sufficient water supply is available, except where steam coal is very cheap and obtainable in large quantities.

Even in some localities where steam turbine plants are used, it might prove, on special investigation, that a hydro-electric plant would furnish cheaper power, but, owing to the impossibility of determining, offhand, without such special investigation the cost of hydro-electric developments, the power cost as for a steam plant was used.

Type 3, Producer gas engine-electric stations were used in a few cases in localities where steam coals are expensive and hard to obtain, and where low grade fuel, such as lignite and peat, are available.

Type 4, Natural gas-engine-electric stations were omitted principally on account of the indefinite nature of the supply of natural gas, and also on account of the high first cost and rather unsatisfactory conditions in the present stage of development of the gas engine from an operating standpoint.
Type 5, Crude oil engine-electric stations. It was necessary to omit these also, owing to the recent advance in the price of crude oil to two and three times its former value, making the cost so high as to be prohibitive in competition with other types of stations.

Type 6, Gas engine-electric stations using producer gas with coke by-product were omitted, owing to the unsatisfactory operation of gas engines, as well as the high first cost of plant.

In an investigation, in which the writer took part recently on a plant of this type, it was found that, figuring the cost of the gas to the gas engine at nothing, the cost of power with a gas engine plant was greater than it could be developed for in a steam turbine plant located at the mines.

Type 7, Steam turbine-electric stations, burning fuel oil. These were also omitted from consideration, owing to the high and fluctuating price of oil.

Type 8, Steam turbine-electric stations burning natural gas were omitted from consideration owing to the indefinite nature of the supply of natural gas.

9. Costs.— On Plate I are given curves showing the cost of power per kilowatt-hour for the different types of plants used. Curves are plotted on a cost of fuel per 1,000,000 British Thermal Units base, in the case of fuel consuming plants; and on a first cost of plant per kilowatt base for hydraulic plants. All plants were assumed to be of at least 100,000 kilowatt capacity, and the load factor was taken at 70 per cent.

1. Steam Turbine-Electric Stations Burning Coal

First cost per kilowatt ............... $50.00
Boiler and furnace efficiency ...... 75 per cent.
Steam, per kilowatt hour .......... 16½ pounds.
Fixed Charges - 11 per cent = 0.089¢ per kilowatt hour
Operating expenses, exclusive of fuel = 0.133¢ per kilowatt hour
Total operating charges, exclusive of fuel = 0.222¢ per kilowatt hour.
PLATE I.
Cost of Power per Kilowatt-hour.

<table>
<thead>
<tr>
<th>Cost of Fuel per 1,000,000 B.T.U. - Cents.</th>
<th>0.00</th>
<th>0.10</th>
<th>0.20</th>
<th>0.30</th>
<th>0.40</th>
<th>0.50</th>
<th>0.60</th>
<th>0.70</th>
<th>0.80</th>
<th>0.90</th>
<th>1.00</th>
<th>1.10</th>
<th>1.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Plant per Kilowatt - Dollars.</td>
<td>0.00</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td>175</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Steam Turbine- Electric Stations
- Producer Gas Engine- Electric Stations
- Crude Oil Engine- Electric Stations
- Hydro-Electric Stations
2. Producer Gas Engine-Electric Station.

First cost per kilowatt ............. $90.00

British Thermal Units of fuel
per kilowatt = 20 000 B.T.U.

Fixed Charges - 12 per cent = 0.175¢ per kilowatt hr.

Operating expenses, exclusive of fuel = 0.140¢ per kilowatt hr.

Total operating charges, exclusive of fuel = 0.315¢ per kilowatt hr.

3. Crude Oil Engine-Electric Plants.

First cost per kilowatt ............. $90.00

Thermal efficiency of plant ......... 27 per cent

Fixed charges - 11 per cent = 0.171¢ per kilowatt hr.

Operating expenses, exclusive of fuel = 0.10¢ per kilowatt hr.

Total operating charges, exclusive of fuel = 0.27¢ per kilowatt hr.


Fixed charges - 11 per cent.

Operating expenses 0.02¢ per kilowatt hr.

Table IV develops the first cost and operating costs of power generating stations for the different groups.

Column a, Group numbers.

Column b, Total capacity of power plants, as obtained from Table III, Column j.

Column c; Types of plants selected for each group.

Column d, Capacity of plants of different types, given in Column c.

Column e, Cost of fuel per ton of 2 000 pounds.
<table>
<thead>
<tr>
<th>a</th>
<th>Total Capacity of Power Plants</th>
<th>b</th>
<th>Type of Plants</th>
<th>c</th>
<th>Capacities of Different Types of Plants</th>
<th>d</th>
<th>Cost of Fuel per 2000 Pounds</th>
<th>e</th>
<th>Cost per 1000 000 B.T.U.</th>
<th>f</th>
<th>Fuel Content of Fuel per B.T.U.</th>
<th>g</th>
<th>First Cost of Power per Kw.Hr.</th>
<th>h</th>
<th>Cost of Plant per Kw.</th>
<th>i</th>
<th>First Cost of different Types of Plants.</th>
<th>j</th>
<th>Cost of different Types of Plants.</th>
</tr>
</thead>
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<td>I</td>
<td>862 000</td>
<td></td>
<td>Water</td>
<td>150 000</td>
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<td>---</td>
<td>--</td>
<td>---</td>
<td>2.50</td>
<td>14 000</td>
<td>8.95</td>
<td>0.20</td>
<td>100</td>
<td>15 000 000</td>
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<td>90</td>
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**TABLE IV.**

**POWER PLANT COSTS.**
<table>
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<tr>
<th>Group</th>
<th>Total First Cost of Plants</th>
<th>Load Factor on Power Plants</th>
<th>Power Output per Year Millions Kw.Hrs.</th>
<th>Operating Charges</th>
<th>Depreciation Taxes and Insurance</th>
<th>Operating Expenses</th>
<th>Total Operating Charges</th>
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<td>.265</td>
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</tbody>
</table>
Column f, Heat content of fuel per pound.

Column g, Cost of fuel per 1,000,000 British Thermal Units.

Column h, Cost of power per kilowatt hour, as obtained from Plate I.

Column i, Assumed first cost of power plant per kilowatt.

Column j, First cost of power plants.

Column k, Total first cost of power plants for each group.

Column l, Load factor of power plants for each group as obtained from Table III, Column k.

Column m, Total kilowatt hours developed per year.

Column n, Interest charge in per cent.

Column o, Interest charge in dollars.

Column p, Charge for depreciation, taxes and insurance, per cent.

Column q, Charge for depreciation, taxes and insurance, dollars.

Column r, Operating expenses per kilowatt hour.

Column s, Operating expenses, dollars.

Column t, Total operating charges, dollars.

IV. TRANSMISSION LINES.-

10. Length.- Transmission line voltage was taken at 150,000 volts. Assuming the most economical distance of power transmission to be 200 miles based on 750 volts per mile of transmission, the theoretical, or average distance apart of power stations, would be

$$2 \times \sqrt{200^2} + 2 = 288 \text{ miles, or say, 300 miles.}$$

Then, in order to have all power plants connected with adjacent ones by trunk lines, would require (2 x 300) = 600 miles of transmission trunk lines for each 90,000 (300 x 300) square miles of territory covered; or for all of the United States -
\[ \frac{2000947159}{90000} \times 600 = 3275 \text{ miles of trunk transmission lines.} \]

Allowing 25 miles for transmission from sub-stations, would make it necessary to have branch transmission lines from the trunk lines every 50 miles, running in one direction only, i.e. North and South, and the total miles of branch transmission lines for the whole of the United States would be as follows:

- Average breadth of the United States, North and South = 1200 miles
- Average length of the United States, East and West = 2250 miles

Number of branch lines running North and South = \( \frac{2250}{50} \times 49 \)

Less number of trunk lines = \( \frac{2450}{300} = 8 \)

Net number of branch lines = 41

Total length of branch lines = (1200 - 50) x 41 = 47200

11. Cost.—Taking the cost of construction of the trunk transmission lines at $25,000.00 per mile, and of the branch transmission lines at $8,000.00 per mile, as is substantiated by data available, the total cost of transmission lines is as follows:

- 3275 miles trunk transmission lines @ $25,000 per mile = $81,900,000
- 47,200 miles branch transmission lines @ $8,000 per mile = $378,000,000

Total cost of all transmission lines to serve the railways of the United States = $459,900,000

12. Operating Charges.—The operating charges are assumed as follows:

- Interest at 5 per cent = $22,995,000
- Depreciation, taxes, and insurance at 4 per cent = $18,396,000
- Maintenance at 2 per cent = 9,198,000
- Energy losses at 10 per cent of $299,074,100 = 29,907,410
  (Table 4, Column t)
- Total operating charges = $80,496,410
V. SUB-STATIONS.

13. General.-- It is assumed that all present steam lines would be operated by means of transformer sub-stations, and that all present electric lines would be operated by means of motor generator sub-stations.

The total capacity of sub-stations and power losses are determined as follows:

Steam Railroads:

Kilowatt-hours per year,
Table III, Col. c, ......................... = 59 237 000 000

Power Factor ................................ 62%
Overload capacity ........................... 25%
Transmission losses from sub-stations 10%

Total capacity transformer

\[
\text{Sub-stations} = \frac{59\,237\,000\,000}{8760 \times .62 \times 1.25 \times .90} = 9\,700\,000 \text{ kilowatts.}
\]

Yearly output of transformer

\[
\text{Sub-stations} = \frac{59\,237\,000\,000}{.90} = 65\,820\,000\,000 \text{ kilowatt-hrs.}
\]

Taking transformer efficiency at 97%, the yearly energy losses of transformer

\[
\text{substations} = 65\,820\,000\,000 \times \frac{3}{97} = 2\,034\,000\,000 \text{ kilowatt-hours.}
\]

Electric Railways:

Kilowatt-hours per year, Table III,
Column d ................................. = 5\,525\,700\,000

Power factor ................................ = 30%
Overload capacity ........................... = 25%
Transmission losses from sub-stations = 10%
23.

Total capacity of motor-generator
Sub-stations = \(\frac{5 \times 525 \times 700}{8760 \times 0.30 \times 1.25 \times 0.90}\) = 1 873 000 kilowatts.

Yearly output of motor-generator
Sub-stations = \(\frac{5 \times 525 \times 700 \times 0.90}{0.873}\) = 6 140 000 000 Kilowatt-hours.

Taking motor-generator substation efficiency at 91%, the yearly energy losses of motor-generator sub-stations =
\[6 140 000 000 \times \frac{9}{91} = 607 000 000\] kilowatt-hours.

14. Transformer Sub-station Costs.— The first cost of transformer stations was taken at $12.00 per kilowatt, therefore
First cost = 9 700 000 kilowatts @ $12.00 per kilowatt = $116 400 000
The operating costs were assumed as follows:-

- Interest at 5% \(= 5 820 000\)
- Depreciation, taxes and insurance at 5% \(= 5 820 000\)
- Operating expenses, exclusive of power losses, 65 820 000 000 kilowatt-hours at 0.10¢ per kilowatt-hour \(= 65 820 000\)
- Energy losses 2 034 000 000 kilowatt-hours @ \((0.32-1/3 + 10\%) \times 0.356\)$ per kilowatt-hour \(= 7 250 000\)
- Total operating charges \(= 84 710 000\)

15. Motor-generator sub-station Costs.— The first cost of motor-generator sub-stations was taken at $30.00 per kilowatt, therefore we have -

First cost of motor-generator sub-stations 1 873 000 kilowatts, @ $30.00 per kilowatt \(= 56 190 000\)
- Interest @ 5% \(= 2 809 500\)
- Depreciation, taxes and insurance @ 5% \(= 2 809 500\)
TABLE V.

SUB-STATION COSTS

For all Railways in the United States, Electrified.

<table>
<thead>
<tr>
<th>Type Sub-station</th>
<th>First Cost</th>
<th>Interest</th>
<th>Depreciation Taxes and Insurance</th>
<th>Operating Expenses</th>
<th>Energy Losses</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer</td>
<td>$116,400,000</td>
<td>$5,820,000</td>
<td>$5,820,000</td>
<td>$65,820,000</td>
<td>$7,250,000</td>
<td>$84,710,000</td>
</tr>
<tr>
<td>Motor-generator</td>
<td>56,190,000</td>
<td>2,809,500</td>
<td>2,809,500</td>
<td>9,210,000</td>
<td>2,160,000</td>
<td>16,989,000</td>
</tr>
<tr>
<td>Total</td>
<td>$172,590,000</td>
<td>$8,629,500</td>
<td>$8,629,500</td>
<td>$75,030,000</td>
<td>$9,410,000</td>
<td>$101,699,000</td>
</tr>
</tbody>
</table>
Operating expenses, exclusive of power losses, 6 140 000 000 kilowatt-hours, @ 0.15¢ per kilowatt-hour ................. $9 210 000

Energy losses (607 000 000 kilowatt-hours) @ 0.356¢ per kilowatt-hour ........ 2 160 000

Total operating charges .......................$16 989 000

16.- Total Sub-station Costs.-- Table V gives the summarized cost data on Sub-stations.

VI. Electrification of Tracks and Equipment of Present Steam Railroads.--

17.- Cost of Electrification of Tracks.-- The costs of electrification of tracks as contained in Table VI are the most accurate figures obtainable from the data available:--

<table>
<thead>
<tr>
<th>Number of Tracks</th>
<th>Number of Miles</th>
<th>Cost to Electrify Per Mile</th>
<th>Total Cost of Electrification</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1 488.78</td>
<td>$25 000.</td>
<td>$ 37 230 800.</td>
</tr>
<tr>
<td>3</td>
<td>717.61</td>
<td>15 000.</td>
<td>10 755 050.</td>
</tr>
<tr>
<td>2</td>
<td>19 452.35</td>
<td>10 000.</td>
<td>194 523 000.</td>
</tr>
<tr>
<td>1</td>
<td>219 172.01</td>
<td>4 000.</td>
<td>876 800 000.</td>
</tr>
<tr>
<td>Yard and Sidings</td>
<td>85 581.93</td>
<td>2 000.</td>
<td><strong>171 450 000.</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1 290 758 850.</td>
</tr>
</tbody>
</table>

18.- Costs of Electric Locomotives.-- In the report of the Interstate Commerce Commission we find that the heating surface of all the steam locomotives in service during 1910 was 125 195 129 square feet. Taking the figure as given by W.F.M.Goss of 0.43 H.P.
per square foot of heating surface, would make the horse power of all the locomotives in service \(0.43 \times 125 \times 195 \times 129 = 53\,800\,000\) horse power.

From the data available, it is fair to assume that electric locomotives could be purchased in quantities for $20.00 per horse power, which would make the cost of electric locomotives

\[53\,800\,000 \times \$20.00 = \$1\,076\,000\,000.\]

19.- Operating Expenses of Electrified Steam Railroads.—
The principal factors in the operating expenses of steam railroads, which are affected by electric operation, are —

1. Maintenance of permanent way.
2. Repairs and renewals of locomotives.
3. Engine and roundhouse wages.
4. Fuel and power for trains.
5. Miscellaneous items.
6. Repairs and renewals of overhead work.

The accompanying Table VII, Column a, gives the operating charges for all steam railroads of the United States, as taken from the Interstate Commerce Commission Reports, and divided in accordance with the above named items. Taking the items up in order we have the following statement by J. Shaw, before the British Institute of Civil Engineers, Nov. 1909.— "Mercy railway records for three years of steam traction show that the effect of electric traction on the maintenance of the permanent way has been to reduce the cost of maintenance per ton-mile from 0.0416 cents to 0.0240 cents." This is equivalent to a saving of 42.3%.

This figure for the railroads of the United States for 1910
was 0.032 cents per ton-mile which, if reduced to 0.024 cents per ton mile is equivalent to a saving of 25%, which figure has been used.

As to the second item, Repairs and renewals of locomotives,- Stillwell states that the maintenance and up-keep of electric locomotives may be placed at 2½% per annum, while the rate for steam locomotives is 20% per annum, which, when considering the cheaper cost of steam locomotives, is equivalent to a saving of 80%.

Pomerey states the reduction in maintenance cost of electric locomotives below steam locomotives is 60%.

Burch makes the reduction 47.8%.

Taking the average of this data makes the saving in repairs and renewals of locomotives 62.6%.

Burch summarized the saving effected by electric traction due to reduction in engine and roundhouse wages at 36%.

The same authority places the saving on all other items, except fuel and power for trains, at 24½% and makes an addition of 1% of the total for repairs and renewals of overhead work.

The proper allowances, in accordance with this data, have been made in Table VII.

20.- Fixed Charges for Electric Locomotives.—Taking the interest charge for electric locomotives at 5%, we have -

Interest charge for electric locomotives = $1 076 000 000 @ 5% ................. = $53 800 000

Depreciation of electric locomotives is already taken care of under heading VI-19 "Operating Expenses of Electricized Steam Railroads".

Taking taxes and insurance at 2%, we have
taxes and insurance charge for electric locomotives = $1 076 000 000 @ 2% ........ = 21 520 000
### TABLE VII.

Operating Costs of Electrified Steam Railroads in the United States.

<table>
<thead>
<tr>
<th>Item</th>
<th>Steam Operation United States 1910</th>
<th>Electric Operation</th>
<th>Operation Cost by Electric Traction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance of Way and Structures</td>
<td>$368 394 260</td>
<td>25 $92 300 000</td>
<td>$276 094 260</td>
</tr>
<tr>
<td>Repairs and renewals of locomotives</td>
<td>156 253 231</td>
<td>62.6 92 900 000</td>
<td>63 353 231</td>
</tr>
<tr>
<td>Engine and Roundhouse Wages</td>
<td>178 192 968</td>
<td>36 64 100 000</td>
<td>114 092 968</td>
</tr>
<tr>
<td>Fuel and power for trains</td>
<td>231 573 851</td>
<td>100 231 573 851</td>
<td>-</td>
</tr>
<tr>
<td>Miscellaneous items</td>
<td>887 836 513</td>
<td>2½ 22 200 000</td>
<td>865 636 513</td>
</tr>
<tr>
<td>Repairs and renewals of overhead</td>
<td>work -2-1</td>
<td>-1 -18 222 508</td>
<td>18 222 508</td>
</tr>
<tr>
<td>Total</td>
<td>$1 822 250 823</td>
<td>26.6 $484 851 343</td>
<td>$1 337 399 480</td>
</tr>
</tbody>
</table>

21. - Fixed Charges for Electrification of Roadway. — Taking the interest charge at 5%, we have —

Interest charge for electrification of roadway = 1 290 758 850 @ 5% = 564 537 942

Taking depreciation, taxes and insurance at 4%, we have —

Depreciation, taxes and insurance for electrification of road = 1 290 758 850 @ 4% = 51 630 354
VII. Deductions and Allowances.-

22.- General.-- In making allowances for capital investment in present electric power generating stations, present steam locomotives, and such other items as would be displaced by joint electrification, a deduction was made for their probable present value. In reality, however, should a project of this sort be attempted, the equipment thus displaced would be worn out in service, and result in a decrease of the depreciation charges as a whole, but the result would be the same.

23.- Allowances for Present Electric Railway Power Plants.-- Assuming that the total normal rating of power plants which serve present electric railways is the same as that calculated for motor generator sub-stations under heading V-13, and taking the present average value of these power plants at $55.00 per kilowatt, we have:

Capital allowance for present electric railway power plants
1 873 000 kilowatts @ $55.00 per kilowatt.. = $103 000 000

Interest allowance for present electric railway power plants @ 5% .................. = 5 150 000

Depreciation, taxes and insurance, allowance for present electric railway power plants @ 6% .......................... = 6 180 000

Taking the operating cost of present electric railway power plants at 3¢ per car-mile, the allowance is $0.03 x 2 124 660 000 .... = 63 739 800

Total allowance for operating charges of present electric railway power plants ...... = $ 75 069 800
24.- Allowances for Present Steam Locomotives.-- The total horse power of all present steam locomotives has already been assumed to be 53,800,000, heading VI-18. Taking the average value per horse power at $12.00, we have -

Capital allowance for present steam locomotives 53,800,000 horse power @ $12.00 per horse power $645,600,000

Interest allowance for present steam locomotives @ 5% 32,280,000

Taxes and insurance allowance for present steam locomotives @ 2% 16,140,000

Allowance for depreciation and operation has been made under heading VI-19, "Operating Expenses of Electrified Steam Railroads".

Total allowance for operating charges except depreciation and operating expenses $48,420,000

25.- Allowances for Present Electrified Portion of Steam Railroads.--Burch in his treatise on "Electric Traction for Railway Trains" gives estimated costs of steam railroads in the United States which have been electrified, by the close of 1910, as $69,500,000.

Assuming that this expenditure is divided as follows, we have the following costs on the portion of the steam railroads in the United States which were electrified at the close of 1910.

Power Plants 30% = $20,850,000
Sub-stations 5% = 3,475,000
Lines 45% = 31,275,000
Motor equipment 20% = 13,900,000
Total $69,500,000
We have then -

a - Deductions due to Power Plants of Present Electrified Portion of Steam Railroads -

Capital .............................................$20,850,000
Fixed Charges, interest @ 5% ........ 1,042,500
Depreciation, taxes and
insurance @ 6% .................................. 1,051,000
Total fixed charges ...................... $2,093,500

Operating Expense is included
under heading VI-19.

b - Deductions due to Sub-stations -

Capital .............................................$3,475,000
Fixed charges, interest @ 5% ...... 173,750
Depreciation, taxes and
insurance @ 6% ............................... 173,750
Total Fixed Charges ..................... $347,500

Operating expense is included
under heading VI-19.

c - Deductions due to Electrification of Lines -

Capital .............................................$31,275,000
Fixed charges, interest @ 5% ........ 1,563,750
Depreciation, taxes and
insurance @ 4% ............................... 1,251,000
Total fixed charges ..................... $2,814,750

Operating expense is included
under heading VI-19.

d - Deductions due to Motor Equipment -

Capital .............................................$13,900,000
Fixed charges, interest @ 5% ...... 695,000
Depreciation is included under
heading VI-19
Taxes and insurance @ 2% .............. 278,000
Total fixed charges, except depreciation... $973,000
Operating expense is included under heading VI-19.

VIII. Summary and Conclusions.

26. - Summary. - Table VIII is a summary of all the first costs, fixed charges and operating expenses, entering into the joint electrification of all the steam and electric railroads of the United States as of June 30, 1910. The table gives the total costs for joint electrification, the deductions therefrom for considerations treated under heading VII, and the net amounts, separately, for all of the items entering into the subject, as well as a grand total of all these items, which is as follows:

- Total additional capital required for joint electrification of all railways in the United States: $3,178,608,855
- Interest - 5%: $158,930,442
- Depreciation, taxes and insurance: $136,009,104
- Total Fixed Charges on additional investment: $294,939,546
- Total Operating Expenses: $1,585,499,790
- Total charges against electrification: $1,880,438,736

27. Conclusions. - The total operating expenses for all steam railroads in the United States for year ending June 30, 1910 were, see Table VII: $1,822,250,823

The total operating expenses for all electric railroads in the United States during 1910 were, see Table I, Column h: 323,780,000

Total operating expenses for all steam and electric railroads in the United States in 1910: $2,146,030,823

Total charges against joint electrification of all railways in the United States, Table VIII: $1,880,438,736

Saving by joint electrification: $265,592,087
<table>
<thead>
<tr>
<th>Item</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Plants</strong> -</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$997</td>
<td>$49</td>
<td>$60</td>
<td>$188</td>
<td>$299</td>
<td>074</td>
</tr>
<tr>
<td>Deductions</td>
<td>103</td>
<td>5</td>
<td>6</td>
<td>63</td>
<td>75</td>
<td>069</td>
</tr>
<tr>
<td>Deductions</td>
<td>20</td>
<td>051</td>
<td>000</td>
<td></td>
<td></td>
<td>000</td>
</tr>
<tr>
<td>Net</td>
<td>873</td>
<td>43</td>
<td>53</td>
<td>124</td>
<td>221</td>
<td>910</td>
</tr>
<tr>
<td>Transmission Lines - Total</td>
<td>459</td>
<td>22</td>
<td>18</td>
<td>39</td>
<td>80</td>
<td>496</td>
</tr>
<tr>
<td>Deductions (See Roadway)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-stations - Total</td>
<td>172</td>
<td>8</td>
<td>8</td>
<td>84</td>
<td>101</td>
<td>699</td>
</tr>
<tr>
<td>Deductions</td>
<td>3</td>
<td>173</td>
<td>173</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>169</td>
<td>11</td>
<td>8</td>
<td>84</td>
<td>101</td>
<td>351</td>
</tr>
<tr>
<td>Locomotives - Total</td>
<td>1</td>
<td>52</td>
<td>16</td>
<td>278</td>
<td>973</td>
<td>000</td>
</tr>
<tr>
<td>Deductions</td>
<td>416</td>
<td>695</td>
<td>278</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>416</td>
<td>20</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadway - Total</td>
<td>1</td>
<td>693</td>
<td>1</td>
<td>137</td>
<td>141</td>
<td>576</td>
</tr>
<tr>
<td>Deductions</td>
<td>31</td>
<td>1,563</td>
<td>1,251</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>1</td>
<td>259</td>
<td>50</td>
<td>1,337</td>
<td>1,480</td>
<td>753</td>
</tr>
<tr>
<td>All Items - Total</td>
<td>3</td>
<td>578</td>
<td>161</td>
<td>1,649</td>
<td>218</td>
<td>238</td>
</tr>
<tr>
<td>Deductions</td>
<td>818</td>
<td>40</td>
<td>25</td>
<td>63</td>
<td>129</td>
<td>718</td>
</tr>
<tr>
<td>Net Amounts for Electrification</td>
<td>3</td>
<td>178</td>
<td>136</td>
<td>1,585</td>
<td>1,880</td>
<td>438</td>
</tr>
</tbody>
</table>

* Taxes and insurance only.

x Except depreciation and operation.
Interest charge included in electrification charges ............... $ 158,930,442

424,522,529

In other words joint electrification would pay

\[
\frac{424,522,529}{3,178,608,850} = 13-1/3\% \text{ on the investment.}
\]

This is highly gratifying for the joint electrification of all railways when considered in connection with the many other advantages and the likely increase in revenue which would result, and apparently the subject is worthy of a more detailed investigation.