17 November, 1914.

BENJAMIN HALL BLYTH, M.A., President, in the Chair.

The PRESIDENT, in announcing the death of Mr. E. B. Ellington, Member of Council, said that at their meeting that day the Council had passed the following resolution:—"That the Council record the very deep regret with which they have learned of the death of their esteemed colleague, Mr. Edward Bayzand Ellington, and desire to convey to Mrs. Ellington and the other members of his family an expression of warm sympathy with them in their bereavement." He was sure that every member of The Institution would concur in that resolution.

(*Paper No. 4119.*)

"Economics of Electric Railway Distribution."

By HORACE FIELD PARSHALL, D.Sc., M. Inst. C.E.

THE problems incident to the design of an electric-traction installation are referable to the predetermined train-movement. By train-movement is meant the space-time characteristic of the different classes of equipment, the tonnage referable thereto, and the general schedule of train-service. Allowing for such differences as may occur in the design of electrical equipment of the trains and rolling stock, the energy-consumption per ton-mile follows from the space-time characteristic of the trains. The total consumption of energy for traction purposes follows from the summation of the ton-mileage referable to the different classes of equipment, and the load-factor from the characteristics of the train-equipment and the tonnage determined by the train-schedule. The load-factor and the energy-consumption being known, the amount of power, as also the capacity of the transmitting mains, follows as a result, allowing, of course, such margins for emergencies or special conditions of working as experience has shown proper for any particular class of train-service.

Practically all modern traction systems of the larger class are referable to the same class of power-house and transmission system. There are differences due to different phase-characteristics, since with rotary-converter or synchronous-motor sub-station plant, the power-factor in the transmitting mains may be maintained at unity, whereas with static-transformer conversion only, as in the case of single-phase and three-phase locomotion, the power-factor falls below unity, so that larger mains and generators would be required to secure the same output and efficiency of transmission. It is necessary to make this reservation as to phase-difference, since the effect of low power-factor on the spacing of the sub-stations is of the same nature as increased load.

For the purposes of this Paper it is assumed that all the different systems are on the same basis, power-house and transmission considered, and that the main features of these follow from the train-movement and a correct solution of the different problems to give the most economic supply up to the sub-stations, suitably arranged. Assuming, therefore, high-tension transmission, the remaining problem relates to the capacity and spacing of the sub-stations. The transmission and generation is not affected by the sub-station arrangement to any important extent, except with the reservation made, so that the sub-station arrangement has to be determined with reference to variations in the operating result occasioned by spacing and capacity. With the given energy-consumption per unit of length of line that follows from a given train-movement, the capacity of the sub-stations increases directly with the distance between them. The energy-loss in distribution-conductors of a given section varies with the cube of the distance between sub-stations. The cost of attendance is, within wide limits, independent of the size of sub-stations. Maintenance and renewals per kilowatt is more or less constant. The cost of the plant per kilowatt falls off with the size of the units.

This Paper has been prepared to show graphically the arrangement of sub-stations that will operate different train-services with minimum total operating-cost. The Author takes as a basis railway records that have been accurately kept over a period of years. The Central London was the earliest railway to make use of large rotary converters, and accurate records, as to expenditure and performance of the sub-stations, have been kept since the railway was opened in 1900. The records relate to all expenditure for labour, supplies, and maintenance, and the energy-loss is known from the system of metering. These records have been compared with those available for other railways, with which they are found to be in general agreement. Taking these results, therefore, as a basis, Tables have been prepared showing under what conditions of spacing the best economy would be obtained. These Tables are appended to the Paper, so that all of the conditions on which the different curves are founded may be known. The Tables have been extended to include different train-services and different working-voltages. Synchronous motor-generator results are not brought into the Paper, as the capital cost and energy-loss are excessive as compared with rotary converters, with no attendant operative advantages, except at voltages in excess of those considered. The assumption as to rotary converters is that the design will be such that the over-compounding will compensate for line and transformer inductance drop in the distribution circuit, and that full load can be carried indefinitely, double load for periods of an hour, and triple load under the reasonable exigencies of a traction load. These are conditions being met by the improved apparatus now in use. The Central London machines were the first of so large a size. They will work intermittently at double load, and for considerable periods at 50 per cent. overload. The improvements since that apparatus came into use are principally due to the interpoles, which allow greater compounding and greater overloads and higher working-voltages.

In the case of continuous-current working, the working-voltages have been taken at 600, 1,200, and 2,400 volts, these being more or less standard. The Author has not extended the Tables, etc., to include higher direct-current voltages, since the commercial advantages are not apparent, and standardization has not proceeded so far that operating-results can be definitely assumed. He has taken as an example a railway 36 miles long, because with this length of line a normal distribution of sub-stations is possible in every case. A double line is assumed, since this provides the necessary facilities for the different train-movements dealt with. The assumptions do not extend beyond what may be termed the train-conducting system, as the mechanical arrangements may be varied widely, according to local arrangements, without affecting in any way the efficiency of the electrical arrangements. The general line of progress being to include traction systems as a part of more general systems of electrical distribution, and the class of conversion plant necessary to comply with the requirements of traction work admitting of wide differences as to voltage and frequency, it is unnecessary to assign close limits to either voltage or frequency. Rotary converters complying with the general conditions assumed are available for frequencies from 25, as taken in the days of steam-engine drive, to 50 or 60 cycles, as equally satisfactory with turbine drive. The same wide range is permissible in transmission-voltage, without vitiating any of the conclusions of the Paper, as the performance and cost of transformers varies but little with any voltage suitable to a transmission system that could properly be a part of a traction installation. There are economical conditions peculiar to the traction system *per se*, independent of the wider problems that enter into a general system of generation and transmission, and the object of this Paper is to deal with these conditions.

For the solution of the general problems it is necessary to assume some definite figure for the cost of energy. This has been taken at a flat rate of 0·5*d.* per kilowatt-hour. The assumption of this figure must not be taken as an expression of the Author's opinion whether it is a fair price for a company to buy or generate at. If the figure is taken too high, it can only lead to an electrical system slightly higher in efficiency than it need be to comply strictly with the economic conditions, capital expenditure and energy-loss considered. The trains are taken in all cases as having an average weight of 100 tons loaded. The stopping-places are taken at 1 mile apart, and a schedule speed of 16 miles per hour, with stops of 20 to 30 seconds each, is assumed. The energy-consumption of the trains, including current for lighting, braking-equipments, and heating, is taken at 70 watt-hours per ton-mile as measured at the direct-current bars of the sub-stations.

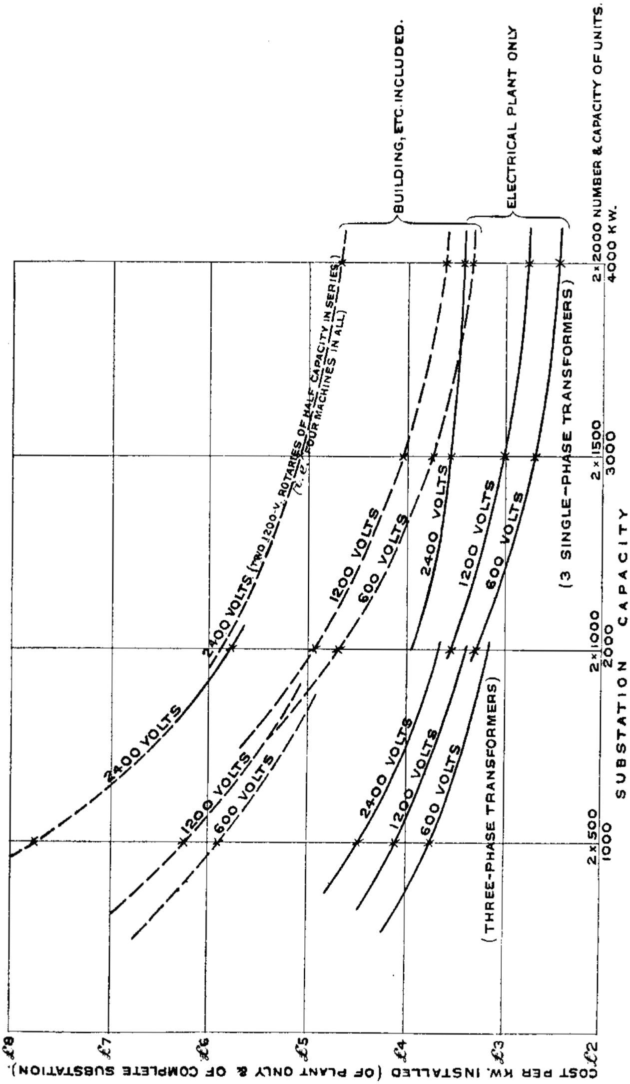
The following effects of certain variations in these conditions may be noted. For example, if the energy-consumption is taken rather lower, but the average train-weight is increased proportionately, the figures in the Tables and the results remain exactly the same. If the average train-weight is taken as 125 tons, for example, and the energy-consumption as 56 watt-hours per ton-mile, the final results are not affected. Again, if the schedule speed is increased, this would decrease the average number of trains supplied from one sub-station at any instant; but if, at the same time, the train-frequency is increased during the "rush hours," instead of a uniform service being assumed, the final result will again be approximately the same. These examples are mentioned as showing the flexibility of the Tables. These factors also, namely, train-weight and schedule speed, are the only assumed conditions, variations of which would seriously affect the final results.

Table I (Appendix I) shows the calculations worked out for the condition of a 600-volt conductor, and for the three train-services. Tables II and III show similar calculations for voltages of 1,200 and 2,400 volts respectively. The second column of each Table shows how each item is deduced and makes the Tables almost self-explanatory, but it may be as well to run through the items in some detail.

Item (*a*) gives the particular sub-station spacings for which each case is worked out. Item (*c*), the average number of trains fed at any instant from one sub-station, is deduced directly from the schedule speed, the train-service, and the distance between sub-stations. Item (*d*), the average amperes in the conductor at the sub-station, is obtained directly from the watt-hours per ton-mile and the train-service, thus: the trains per hour, multiplied by the weight of train, multiplied by half the distance between sub-stations, gives the ton-miles per hour over the section of track. Multiplying by the watt-hours per ton-mile, the average power supplied in watts is obtained, from which is deduced the average amperes supplied to that section from the sub-station. The total average amperes (item *e*) fed from one sub-station to the four-track sections is, of course, four times this amount. Item (*f*) is the total output of the sub-station per annum, assuming a 19-hour day. The next item (*g*) in the Table, namely, the maximum demand per sub-station, must be estimated with reference to the train-movement and the probable diversity between the starting loads. With increasing number of trains fed from one sub-station, smaller proportions of the total number are assumed to be starting at the same instant. A starting train is assumed to take 480 kilowatts, and 120 kilowatts is allowed for each of the other trains on the section. Item (*i*) shows the maximum demand per sub-station.

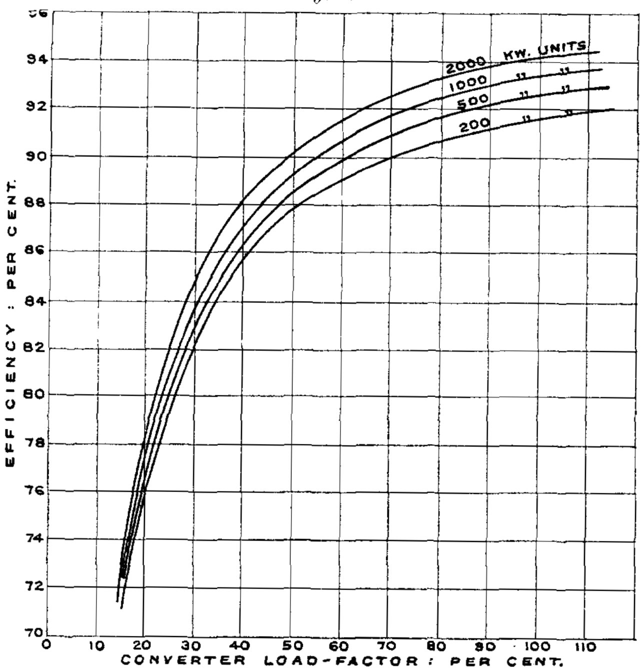
In determining the sub-station capacity the Author has assumed that the instantaneous maximum demand, determined as above, can be dealt with by sub-station plant with a rated capacity of half this amount, but he has taken a plant-capacity 50 per cent. greater than this, to allow for spare plant. This required plant-capacity is divided up among two, three, or four units, in accordance with the size of the sub-station. The total cost of the sub-station is estimated by taking the price per kilowatt from the curves of *Fig. 1.* The full-line curves show the cost of plant only, while the dotted-line curves show the cost of the sub-station complete, including buildings, foundations, etc. In all cases the curves apply to rotary-converter sub-stations supplied with three-phase current at 10,000 to 50,000 volts, 25 to 50 cycles, the total sub-station capacity being divided in each case between two or three units. Separate curves are shown for 600- and 1,200-volt rotary converters, while, in the case of 2,400 volts on the direct-current side, it is assumed that each of the two sub-station units will consist of two 1,200-volt rotaries in series. The next two items (*o* and *p*)

Fig. 1.



show the sub-station load-factors, namely, the ratio of the above maximum demand to the average over 24 and 19 (running) hours respectively. For the purpose of this investigation the train-service is supposed to be uniform and the sub-stations running continuously during the 19 hours, so that this latter 19-hour load-factor will be the same as the load-factor of the individual rotary converters. From this load-factor and the size of the units can be deduced, with the aid of the curves of *Fig. 2*, the annual overall efficiency of the sub-station (q), including both rotary converters and transformers. From this last figure and the total output of

Fig. 2.



the sub-stations can be deduced the energy lost per annum (r) in the sub-station.

The next four items give the annual cost of running the sub-stations. The first item (s) is the capital charge per sub-station at 5 per cent. The next item (t) covers wages, superintendence, and stores. Repairs and renewals (item u) are taken at 0·5 per cent. of the first cost, in accordance with the experience on the Central London Railway. The last item (v) is the value of the units lost in the sub-station at 0·5*d.* per unit. The sum of these four items (w) is the total annual cost per sub-station.

The total section of conductor (C) has been taken in each case at the section corresponding to a maximum current-density at the sub-station of approximately 1,000 amperes. Any variation in section of the conductor will, of course, affect the annual cost of operation for the particular sub-station spacing in question, but the section so chosen is in each case approximately that most suitable. The resistance of this conductor and the track return from the sub-station to the neutral point midway between sub-stations, and back along the track-rails to the sub-station, is next given in the Table (item E), the resistance per mile of the running rails (100 lbs. per yard) being taken at 0·024 ohm.

Item (F), the average watt loss, or the C^2R power-loss in the conductors and rails of the four-track sections, is estimated thus:—The resistance in question is the last item (E). The C^2R loss will be greater than the product of this and the square of the average current (*d*), by the ratio of the mean square current to the square of the mean current. The ratio in these Tables is taken at 1·3, which is an average value determined from suitable load-curves. The actual C^2R loss along the whole section will be only one-third of this calculated C^2R loss, as it is assumed that the current is taken off from the overhead conductor uniformly along the section.

The next item in the Table (G) is the energy-loss per annum in conductor and rail return. The sum represented by this loss, at 0·5*d.* per unit for the whole line, is given in item (J). To this must be added the capital charge (M) on the cost of the overhead equipment taken at 5 per cent. of the first cost (L) as before, and a figure (N) for the maintenance and repairs of the overhead equipment and track-bonding, taken at 3 per cent. of the first cost. The summation of these last three items gives the total costs (O) due to the conductor system, and this figure has to be added to the total cost of running the sub-stations (B), the item (P) being the total sub-station and track costs per annum.

This series of calculations has been made with different distances between sub-stations for each particular service of trains and for each voltage. The various items to be considered are the individual and total sub-station capacity, the section of conductor, cost of sub-stations and overhead structure, and total capital cost for each of the nine cases considered. These are shown plotted against distances between sub-stations, in curves, Figs. 3–20, Plate 2. Figs. 4, 6, 8, 10, etc., show the sub-station and conductor annual costs respectively, and also the total of these two figures plotted as a function of the distance between sub-stations. The lowest point on this last curve indicates the most economical sub-station spacing for the conditions assumed.

Taking the particular case of a service of six trains per hour and a voltage of 600 volts, the results, plotted in Figs. 3 and 4, Plate 2, show that the annual costs are a minimum with a distance of 8½ miles between sub-stations. The results with higher train-frequency are shown plotted in Figs. 4, 5, 6, 7, from which it will be seen that the most economical sub-station spacing is 5·5 miles in the case of a train-service of twelve trains per hour, and 3·25 miles in the case of a train-service of twenty-four trains per hour. This last service corresponds with that obtaining on some of the London Underground railways and the most economical sub-station spacing arrived at, namely, 3·25 miles is approximately that which has been adopted. In the case of the Central London Railway, the distance between sub-stations is rather less, namely, about 2 miles.

The corresponding curves for a working-voltage of 1,200 volts are shown plotted (Figs. 9–14). The most economical sub-station spacings are seen to be 11, 7·5, and 5 miles respectively for the train-services of six, twelve, and twenty-four trains per hour. The curves for a working-voltage of 2,400 volts are shown plotted in Figs. 15–20, the most economical distances between sub-stations arrived at being 16, 12, and 8½ miles for the respective train-services of six, twelve, and twenty-four trains per hour.

The final curves for the total sub-station and conductor annual costs are shown plotted again, in groups, in Figs. 21, 23, and 25, Plate 2. Each group of curves represents the variation in annual costs with sub-station spacing and voltage for a given train-service. The two curves plotted in Figs. 22, 24, and 26 show the increase in the economical distance between sub-stations with higher voltages and the corresponding reduction in the total annual costs respectively.

Fig. 27 shows a series of curves based on the foregoing, from which may be determined the most economical sub-station spacing for any given traffic-density expressed in number of (100-ton) trains per hour and for various voltages. It will be seen from the curves applying to a voltage of 600 volts that with the heaviest service the most economical distance between sub-stations is not less than 2½ miles. If the voltage is 2,400 volts the distance between sub-stations will be about 7 miles. With a service of one train every 15 minutes and a working-voltage of 600 volts, sub-stations should be 10 miles apart. With 2,400 volts and the same service, the sub-stations should be 18 miles apart.

The curves, showing the reduction in total annual cost with higher voltages (Figs. 21–26) are plotted on one sheet and to the same scale in Fig. 28, Plate 3. These illustrate the advantage gained by working at higher voltages and confirm the Author's view that with the present arrangement of rotary-converter sub-stations and the cost of apparatus at present obtaining, there is little advantage in a higher voltage than 2,400 volts for the track conductor. The economy of higher voltages is shown to be approximately the same, whatever the train-service. Thus, as between 600 and 1,200 volts, there is a saving of about 14 per cent. in the total annual costs in each case. As between 1,200 and 2,400 volts, there is a further saving of about 7 per cent. in the annual costs, or 21 per cent. saving as between 600 and 2,400 volts, whatever the train-service. If the working-voltage is further increased to 3,600 volts, there is a decrease in total annual expenditure on sub-station and overhead conductor equipment of only 3 per cent. or less, which will be less than the additional cost of the rolling stock, and materially so in the case of heavier service conditions, where the cost of the rolling stock is a larger portion of the total.

The methods employed in dealing with direct-current installations have been applied in a modified form to single-phase and three-phase installations. The calculations are shown in detail in Tables IV and V for the case of single-phase distribution at 5,000 and 10,000 volts respectively, and in Table VI for three-phase distribution at 5,000 volts. These Tables need no explanation, but it should be noted that the average power-factor in the case of the single-phase system is taken as 0·8, and in the case of the three-phase system at 0·9. The power-factor for a starting train is taken at 0·5 and 0·75 respectively. The cost per kilo-volt-ampere of the single-phase and three-phase sub-station is taken in every case from the curve of Fig. 30, Plate 3. Three-phase and single-phase transformer-stations cost approximately the same, as the cheaper transformers may be assumed to balance the higher cost of switch-gear in the latter case. Fig. 29 gives the curve from which the annual overall efficiency of sub-stations is determined.

The results obtained from these Tables are shown plotted in Figs. 32–49. For single-phase distribution at 5,000 volts, the most economical sub-station spacings are 31, 24, and 16 miles for train-services of two, three, and six trains per hour respectively. It will be noted that this last spacing of 16 miles for 5,000 volts single-phase is the same as that for 2,400-volt direct current for the same service of six trains per hour. At 10,000 volts single-phase the most economical distances between sub-stations increase to 45, 34, and 26 miles for two, three, and six trains per hour respectively.

With three-phase distribution at 5,000 volts, the most economical distances between sub-stations are 38, 31, and 18 miles for the same respective train-services.

It will be seen that, in many cases, the economical distance between sub-stations is greater than would be permissible in practice, from considerations of both traffic-operation and voltage-drop. There exists a wide difference between engineers at the present time as to practical points in operation, particularly in respect of sub-station attendance; the method employed in determining the economic distance is such, however, that new values can easily be obtained for any other conditions besides those assumed.

Fig. 31 shows the most economical sub-station spacing, plotted against the traffic-density expressed in number of (100-ton) trains per hour, for the two different voltages. A comparison of the total costs, associated with the distribution system, in the cases set out in Tables IV, V, and VI, will show that in many cases the lower pressure of 5,000 volts is the most economical, and the higher pressures of 10,000, 12,000, and 15,000 volts, in vogue on the Continent, are explained by considerations of voltage-drop.

The Paper is accompanied by forty-nine diagrams, from which Plates 2 and 3 and the Figures in the text have been prepared, and by the following Appendixes.

[Appendixes.

APPEN

TABLE I.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{600 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 600 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 800 amperes starting, 200 running .	..
i	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 600}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete . . . ,,	From curves
n	,, sub-station . . . . ,,	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d.* per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$\left\{(D + 0{\cdot}024) \times \frac{a}{2}\right\}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times E \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$F \times 7000/1000$
H	Percentage conductor and track loss	$G/f \times 100$
I	Value of loss at 0·5*d.* per unit	$G \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$I \times b$
K	Cost of track-equipment per mile of double-track . . .	..
L	Total cost of track-equipment	$K \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$L \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$L \times \frac{3}{100}$
O	Total charges due to track	$J + M + N$
P	,, sub-station and track charges	$O + B$
Q	,, capital cost of sub-stations and track-equipment .	$A + L$

DIX I.

600-VOLT OVERHEAD CATENARY EQUIPMENT.

6 Trains per Hour in Each Direction.					
4	**6**	**9**	**12**	**18**	*a*
9	6	4	3	2	*b*
3	4·5	6·75	9	13·5	*c*
140	210	315	420	630	*d*
560	840	1,260	1,680	2,520	*e*
2,350,000	3,530,000	5,300,000	7,050,000	10,600,000	*f*
3 starting	3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	*g*
2,400	3,000	3,750	4,500	6,300	*h*
1,440	1,800	2,250	2,700	3,780	*i*
1,080	1,350	1,690	2,025	2,840	*j*
2×500	2×675	2×850	3×675	4×700	*k*
1,000	1,350	1,700	2,025	2,800	*l*
£5·9	£5·4	£4·9	£5·3	£5·0	*m*
£5,900	£7,290	£8,320	£10,720	£14,000	*n*
18·5	22	26·6	29·5	31·7	*o*
23·3	28	33·6	37	40	*p*
79·5	82·5	84·8	86·4	87·2	*q*
610,000	750,000	950,000	1,100,000	1,560,000	*r*
£295	£365	£417	£536	£700	*s*
£680	£690	£700	£720	£740	*t*
£30	£37	£42	£54	£70	*u*
£1,270	£1,562	£1,980	£2,292	£3,250	*v*
£2,275	£2,654	£3,139	£3,602	£4,760	*w*
0·232*d.*	0·181*d.*	0·142*d.*	0·123*d.*	0·108*d.*	*x*
0·732*d.*	0·681*d.*	0·642*d.*	0·623*d.*	0·608*d.*	*y*
9,000	8,100	6,800	6,075	5,600	*z*
£53,000	£43,700	£33,300	£32,160	£28,000	A
£20,475	£15,924	£12,556	£10,806	£9,520	B
0·35	0·50	0·75	1·0	1·5	C
0·121	0·085	0·056	0·042	0·028	D
0·290	0·327	0·360	0·396	0·468	E
9,830	25,000	62,000	121,000	322,000	F
68,810	175,000	434,000	847,000	2,254,000	G
2·95	4·95	8·2	12·0	21·2	H
£144	£365	£905	£1,765	£4,700	I
£1,296	£2,190	£3,620	£5,295	£9,400	J
£3,130	£3,400	£3,850	£4,300	£5,200	K
£113,000	£122,500	£138,500	£155,000	£187,000	L
£5,650	£6,125	£6,925	£7,750	£9,350	M
£3,390	£3,675	£4,145	£4,650	£5,610	N
£10,336	£11,990	£14,690	£17,695	£24,360	O
£30,811	£27,914	£27,246	£28,501	£33,880	P
£166,000	£166,200	£171,800	£187,160	£215,000	Q

TABLE I.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
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f	,, output per sub-station per annum	$\left\{\frac{e \times 600 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 800 amperes starting, 200 running .	..
i	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 600}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete . . . . ,,	From curves
n	,, sub-station . . . . ,,	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$(\text{D} + 0{\cdot}024) \times \frac{a}{2}$
F	Average watts lost in four conductors and tracks	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$
H	Percentage conductor and track loss	$\text{G}/f \times 100$
I	Value of loss at 0·5*d*. per unit	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of track-equipment per mile of double-track . . .	..
L	Total cost of track-equipment	$\text{K} \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$\text{L} \times \frac{3}{100}$
O	Total charges due to track	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and track charges	$\text{O} + \text{B}$
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$

600-Volt Overhead Catenary Equipment—*continued.*

12 Trains per Hour in Each Direction.					
2	3	4	6	9	*a*
18	12	9	6	4	*b*
3	4·5	6	9	13·5	*c*
140	210	280	420	630	*d*
560	840	1,120	1,680	2,520	*e*
2,350,000	3,530,000	4,700,000	7,050,000	10,600,000	*f*
3 starting	3½ st. 1 run.	4 st. 2 run.	4½ st. 4½ run.	6 st. 7½ run.	*g*
2,400	3,000	3,600	4,500	6,300	*h*
1,440	1,800	2,160	2,700	3,780	*i*
1,080	1,350	1,620	2,025	2,840	*j*
2×500	2×675	2×800	3×675	4×700	*k*
1,000	1,350	1,600	2,025	2,800	*l*
£5·9	£5·4	£4·9	£5·3	£5·0	*m*
£5,900	£7,290	£7,840	£10,720	£14,000	*n*
18·5	22	25	29·5	31·7	*o*
23·3	28	31	37	40	*p*
79·5	82·5	84	86·4	87·2	*q*
610,000	750,000	900,000	1,100,000	1,560,000	*r*
£295	£365	£392	£536	£700	*s*
£680	£690	£700	£720	£740	*t*
£30	£37	£40	£54	£70	*u*
£1,270	£1,562	£1,875	£2,292	£3,250	*v*
£2,275	£2,654	£3,007	£3,602	£4,760	*w*
0·232*d.*	0·181*d.*	0·154*d.*	0·123*d.*	0·108*d.*	*x*
0·732*d.*	0·681*d.*	0·654*d.*	0·623*d.*	0·608*d.*	*y*
£18,000	£16,200	£14,400	£12,150	£11,200	*z*
£106,000	£87,400	£70,600	£64,400	£56,000	A
£40,900	£31,850	£27,063	£21,612	£19,040	B
0·35	0·5	0·7	1·0	1·5	C
0·121	0·085	0·061	0·042	0·028	D
0·145	0·164	0·170	0·198	0·234	E
4,930	12,550	23,100	60,600	161,000	F
34,510	87,850	161,700	424,200	1,127,000	G
1·5	2·5	3·44	6	10·6	H
£72	£183	£337	£885	£2,350	I
£1,296	£2,200	£3,033	£5,310	£9,400	J
£3,130	£3,400	£3,760	£4,300	£5,200	K
£113,000	£122,500	£135,000	£155,000	£187,000	L
£5,650	£6,125	£6,750	£7,750	£9,350	M
£3,400	£3,680	£4,050	£4,650	£5,620	N
£10,346	£12,005	£13,833	£17,710	£24,370	O
£51,246	£43,855	£40,896	£39,322	£43,410	P
£219,000	£209,900	£205,600	£219,400	£243,000	Q

TABLE I.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{600 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 600 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 800 amperes starting, 200 running .	..
i	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 600}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete . . . ,,	From curves
n	,, sub-station . . . . ,,	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$(D + 0{\cdot}024) \times \frac{a}{2}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times E \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$F \times 7000/1000$
H	Percentage conductor and track loss	$G/f \times 100$
I	Value of loss at 0·5*d*. per unit	$G \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$I \times b$
K	Cost of track-equipment per mile of double-track . . .	..
L	Total cost of track-equipment	$K \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$L \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$L \times \frac{3}{100}$
O	Total charges due to track	$J + M + N$
P	,, sub-station and track charges	$O + B$
Q	,, capital cost of sub-stations and track-equipment .	$A + L$

600-Volt Overhead Catenary Equipment—*continued.*

24 Trains per Hour in Each Direction.					
1	2	3	4	6	*a*
36	18	12	9	6	*b*
3	6	9	12	18	*c*
140	280	420	560	840	*d*
560	1,120	1,680	2,240	3,360	*e*
2,350,000	4,700,000	7,050,000	9,400,000	14,100,000	*f*
3 starting	4 st. 2 run.	4½ st. 4½ run.	5½ st. 6½ run.	7½ st. 10½ run.	*g*
2,400	3,600	4,500	5,700	8,100	*h*
1,440	2,160	2,700	3,420	4,860	*i*
1,080	1,620	2,025	2,560	3,640	*j*
2×500	2×800	3×675	3×850	4×900	*k*
1,000	1,600	2,025	2,550	3,600	*l*
£5·9	£4·9	£5·3	£4·9	£4·8	*m*
£5,900	£7,840	£10,720	£12,500	£17,300	*n*
18·5	25	29·6	31	32·8	*o*
23·3	31	37·4	39·3	41·5	*p*
79·5	84	86·4	86·9	87·2	*q*
610,000	900,000	1,110,000	1,420,000	2,080,000	*r*
£295	£392	£536	£625	£865	*s*
£680	£700	£720	£740	£760	*t*
£30	£40	£54	£63	£87	*u*
£1,270	£1,875	£2,292	£2,960	£4,340	*v*
£2,275	£3,007	£3,602	£4,388	£6,052	*w*
0·232*d.*	0·154*d.*	0·123*d.*	0·112*d.*	0·103*d.*	*x*
0·732*d.*	0·654*d.*	0·623*d.*	0·612*d.*	0·603*d.*	*y*
36,000	28,800	24,300	23,000	21,600	*z*
£212,000	£141,000	£129,000	£118,000	£104,000	A
£81,800	£54,100	£43,300	£39,500	£36,350	B
0·35	0·70	1·00	1·40	2·0	C
0·121	0·061	0·042	0·0305	0·021	D
0·073	0·085	0·099	0·109	0·135	E
2,480	11,550	30,150	59,300	165,000	F
17,360	80,850	211,050	415,100	1,155,000	G
0·74	1·72	3·0	4·42	8·2	H
£36	£169	£440	£864	£2,410	I
£1,295	£3,040	£5,280	£7,776	£14,460	J
£3,130	£3,760	£4,300	£5,020	£6,100	K
£113,000	£135,000	£155,000	£181,000	£220,000	L
£5,650	£6,750	£7,750	£9,075	£11,000	M
£3,390	£4,050	£4,650	£5,430	£6,600	N
£10,335	£13,840	£17,680	£22,281	£32,060	O
£92,135	£67,940	£60,980	£61,781	£68,410	P
£325,000	*£276,000*	*£284,000*	*£299,000*	*£324,000*	Q

TABLE II.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{1200 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 1200 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 400 amperes starting, 100 running .	..
i	,, kilowatt demand per sub-station . . . . KW.	$\left\{\frac{h \times 1200}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete	From curves
n	,, sub-station	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5d. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$\left\{(\text{D} + 0{\cdot}024) \times \frac{a}{2}\right\}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$
H	Percentage conductor and track loss	$\text{G}/f \times 100$
I	Value of loss at 0·5d. per unit	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of track-equipment per mile of double track . . .	..
L	Total cost of track-equipment.	$\text{K} \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent.	$\text{L} \times \frac{3}{100}$
O	Total charges due to track.	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and track charges	$\text{O} + \text{B}$
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$

1,200-Volt Overhead Catenary Equipment.

6 Trains per Hour in Each Direction.					
4	6	9	12	18	a
9	6	4	3	2	b
3	4·5	6·75	9	13·5	c
70	105	158	210	315	d
280	420	630	840	1,260	e
2,350,000	3,530,000	5,300,000	7,050,000	10,600,000	f
3 starting	3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	g
1,200	1,500	1,875	2,250	3,150	h
1,440	1,800	2,250	2,700	3,780	i
1,080	1,350	1,690	2,015	2,840	j
2×550	2×675	2×850	2×1,000	3×950	k
1,100	1,350	1,700	2,000	2,850	l
£6·1	£5·7	£5·25	£5·0	£4·95	m
£6,700	£7,690	£8,920	£10,000	£14,100	n
18·5	22·2	26·6	29·5	31·7	o
23·3	28·0	33·6	37·0	40·0	p
81·2	82·4	84·8	86·4	87·2	q
550,000	750,000	950,000	1,100,000	1,550,000	r
£335	£385	£446	£500	£705	s
£690	£700	£710	£720	£740	t
£34	£38	£45	£50	£71	u
£1,145	£1,565	£1,980	£2,400	£3,230	v
£2,204	£2,688	£3,181	£3,670	£4,746	w
0·225d.	0·183d.	0·144d.	0·125d.	0·108d.	x
0·725d.	0·683d.	0·644d.	0·625d.	0·608d.	y
9,900	8,100	6,800	6,000	5,700	z
£60,400	£46,200	£35,700	£30,000	£28,200	A
£19,836	£16,128	£12,724	£11,010	£9,492	B
0·175	0·25	0·375	0·5	0·75	C
0·242	0·170	0·114	0·085	0·057	D
0·532	0·582	0·621	0·654	0 729	E
4,510	11,120	26,820	50,000	125,300	F
31,570	77,840	187,740	350,000	877,100	G
1·34	2·2	3·54	4·96	8·28	H
£66	£162	£392	£730	£1,830	I
£594	£972	£1,568	£2,190	£3,660	J
£2,915	£3,050	£3,275	£3,500	£3,950	K
£105,000	£110,000	£118,000	£126,000	£142,000	L
£5,250	£5,500	£5,900	£6,300	£7,100	M
£3,150	£3,300	£3,540	£3,780	£4,260	N
£8,994	£9,772	£11,008	£12,270	£15,020	O
£28,830	£25,900	£23,732	£23,280	£24,512	P
£165,400	£156,200	£153,700	£156,000	£170,200	Q

TABLE II.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{1200 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, *output per sub-station per annum*	$\left\{\frac{e \times 1200 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 400 amperes starting, 100 running .	..
i	,, kilowatt demand per sub-station . . . KW.	$\left\{\frac{h \times 1200}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete	From curves
n	,, sub-station	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d.* per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$(\text{D} + 0{\cdot}024) \times \frac{a}{2}$
F	Average watts lost in four conductors and tracks . . .	$\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}$
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$
H	Percentage conductor and track loss	$\text{G}/f \times 100$
I	Value of loss at 0·5*d.* per unit	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of track-equipment per mile of double track . . .	..
L	Total cost of track-equipment.	$\text{K} \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$\text{L} \times \frac{3}{100}$
O	Total charges due to track.	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and track charges	$\text{O} + \text{B}$
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$

1,200-VOLT OVERHEAD CATENARY EQUIPMENT—*continued.*

12 Trains per Hour in Each Direction.					
4	6	9	12	18	*a*
9	6	4	3	2	*b*
6	9	13·5	18	27	*c*
140	210	315	420	630	*d*
560	840	1,260	1,680	2,520	*e*
4,700,000	7,050,000	10,600,000	14,100,000	21,200,000	*f*
4 st. 2 run.	4½ st. 4½ run.	6 st. 7½ run.	7½ st. 10½ run.	10 st. 17 run.	*g*
1,800	2,250	3,150	4,050	5,700	*h*
2,160	2,700	3,780	4,860	6,840	*i*
1,620	2,025	2,835	3,645	5,130	*j*
2 × 800	2 × 1,000	3 × 950	3 × 1,200	4 × 1,250	*k*
1,600	2,000	2,850	3,600	5,000	*l*
£5·5	£5·0	£4·95	£4·4	£4·3	*m*
£8,800	£10,000	£14,100	£15,840	£21,500	*n*
24·6	29·5	31·7	32·8	35·0	*o*
31·0	37·0	40·0	41·5	44·0	*p*
83·8	86·4	87·2	88·0	88·4	*q*
910,000	1,100,000	1,550,000	1,950,000	2,800,000	*r*
£440	£500	£705	£792	£1,075	*s*
£700	£720	£740	£760	£780	*t*
£44	£50	£71	£80	£108	*u*
£1,895	£2,400	£3,230	£4,060	£5,830	*v*
£3,079	£3,670	£4,746	£5,692	£7,793	*w*
0·157*d.*	0·125*d.*	0·108*d.*	0·097*d.*	0·088*d.*	*x*
0·657*d.*	0·625*d.*	0·608*d.*	0·597*d.*	0·588*d.*	*y*
14,400	12,000	11,400	10,800	10,000	*z*
£79,200	£60,000	£56,400	£47,520	£43,000	A
£27,711	£22,020	£18,984	£17,076	£15,586	B
0·35	0·5	0·75	1·0	1·5	C
0·121	0·085	0·057	0·042	0·028	D
0·29	0·327	0·3645	0·396	0·468	E
9,850	25,000	62,600	121,200	322,000	F
68,950	175,000	438,200	848,400	2,254,000	G
1·5	2·5	4·14	6·0	10·6	H
£144	£365	£914	£1,767	£4,700	I
£1,296	£2,190	£3,656	£5,301	£9,400	J
£3,230	£3,500	£3,950	£4,400	£5,300	K
£116,500	£126,000	£142,000	£158,300	£191,000	L
£5,825	£6,300	£7,100	£7,915	£9,550	M
£3,495	£3,780	£4,260	£4,750	£5,730	N
£10,616	£12,270	£15,016	£17,966	£24,680	O
£38,327	£34,290	£34,000	£35,042	£40,266	P
£195,700	£186,000	£198,400	£205,820	£234,000	Q

TABLE II.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{1200 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 1200 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 400 amperes starting, 100 running .	..
i	,, kilowatt demand per sub-station . . . KW.	$\left\{\frac{h \times 1200}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete	From curves
n	,, sub-station	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5d. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . . . ohm	..
E	Resistance of conductor and track, from sub-station to neutral point . . . . ohm	$\left\{(\text{D} + 0{\cdot}024) \times \frac{a}{2}\right\}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$
H	Percentage conductor and track loss	$\text{G}/f \times 100$
I	Value of loss at 0·5d. per unit	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of track-equipment per mile of double track . . .	..
L	Total cost of track-equipment.	$\text{K} \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent.	$\text{L} \times \frac{3}{100}$
O	Total charges due to track.	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and track charges	$\text{O} + \text{B}$
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$

1,200-Volt Overhead Catenary Equipment—*continued.*

24 Trains per Hour in Each Direction.					
2	4	6	9	12	*a*
18	9	6	4	3	*b*
6	12	18	27	36	*c*
140	280	420	630	840	*d*
560	1,120	1,680	2,520	3,360	*e*
4,700,000	9,400,000	14,100,000	21,200,000	28,200,000	*f*
4 st. 2 run.	5½ st. 6½ run.	7½ st. 10½ run.	10 st. 17 run.	13 st. 23 run.	*g*
1,800	2,900	4,050	5,700	7,500	*h*
2,160	3,480	4,860	6,840	9,000	*i*
1,620	2,610	3,650	5,130	6,750	*j*
2×800	3×900	3×1,200	4×1,250	4×1,700	*k*
1,600	2,700	3,600	5,000	6,800	*l*
£5·5	£5·0	£4·4	£4·3	£3·8	*m*
£8,800	£13,500	£15,850	£21,500	£25,800	*n*
24·6	30·5	32·8	35·0	35·5	*o*
31·0	38·6	41·5	44·2	44·8	*p*
83·8	86·8	87·8	88·5	89·1	*q*
910,000	1,420,000	1,950,000	2,740,000	3,480,000	*r*
£440	£675	£793	£1,075	£1,290	*s*
£700	£740	£760	£780	£800	*t*
£44	£68	£80	£108	£129	*u*
£1,895	£2,960	£4,060	£5,710	£7,250	*v*
£3,079	£4,343	£5,693	£7,773	£9,469	*w*
0·157*d.*	0·111*d.*	0·097*d.*	0·088*d.*	0·081*d.*	*x*
0·657*d.*	0·611*d.*	0·597*d.*	0·588*d.*	0·581*d.*	*y*
28,800	24,300	21,600	20,000	20,400	*z*
£158,400	£121,500	£95,000	£86,000	£77,500	A
£55,422	£39,087	£34,158	£31,092	£28,407	B
0·35	0·70	1·0	1·5	2·0	C
0·121	0·061	0·042	0·028	0·021	D
0·145	0·170	0·198	0·234	0·270	E
4,925	23,100	60,510	161,200	330,200	F
34,475	161,700	423,570	1,128,400	2,311,400	G
0·75	1·72	3·0	5·32	8·2	H
£72	£337	£883	£2,350	£4,810	I
£1,296	£3,033	£5,298	£9,400	£14,430	J
£3,230	£3,860	£4,400	£5,300	£6,200	K
£116,500	£139,000	£158,400	£190,800	£223,500	L
£5,825	£6,950	£7,920	£9,540	£11,175	M
£3,495	£4,170	£4,752	£5,724	£6,705	N
£10,616	£14,153	£17,970	£24,664	£32,310	O
£66,038	£53,240	£52,128	£55,756	£60,717	P
£274,900	£260,500	£253,400	£276,800	£301,000	Q

TABLE III.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..	
b	Number of sub-stations	$36/a$	
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$	
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{2400 \times 2}$	
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$	
f	,, output per sub-station per annum	$\left\{\frac{e \times 2400 \times 7000}{1000}\right\}$	
g	Demand per sub-station	..	
h	Maximum amperes at 200 amperes starting, 50 running .	..	
i	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 2400}{1000}\right\}$	
j	Half above increased by 50 per cent. for spare . . ,,	..	
k	Sub-station units (2 rotaries in series per unit) . . ,,	..	
l	,, capacity . . . . ,,	..	
m	Cost per kilowatt of sub-station complete	From curves	
n	,, sub-station	$l \times m$	
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$	
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$	
q	Annual overall efficiency of sub-station . . . . ,,	From curves	
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$	
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$	
t	Wages, superintendence, and stores	..	
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$	
v	Cost of lost units at 0·5*d.* per unit	$r \times 0{\cdot}5/240$	
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$	
x	Sub-station charge per unit delivered	$w \times 240/f$	
y	Current cost per unit delivered	$0{\cdot}5 + x$	
z	Total sub-station capacity . . . . KW.	$l \times b$	
A	,, capital cost of all sub-stations	$z \times m$	
B	,, cost of running all sub-stations.	$w \times b$	
C	Copper section of contact conductor . . . . . . sq. in.	..	
D	Resistance of conductor per mile . . . . ohm	..	
E	Resistance of conductor and track return from sub-station to neutral point . . . . ohm	$\left\{(\text{D} + 0{\cdot}024) \times \frac{a}{2}\right\}$	
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$	
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$	
H	Percentage conductor and track loss	$\text{G}/f \times 100$	
I	Value of track loss at 0·5*d.* per unit	$\text{G} \times 0{\cdot}5/240$	
J	Total value of track loss for whole line	$\text{I} \times b$	
K	Cost of track-equipment per mile of double track . . .	..	
L	Total cost of track-equipment	$\text{K} \times 36$	
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$	
N	Maintenance of track-equipment at 3 per cent. . . .	$\text{L} \times \frac{3}{100}$	
O	Total charges due to track	$\text{J} + \text{M} + \text{N}$	
P	,, sub-station and track charges	$\text{O} + \text{B}$	
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$	

2,400-VOLT OVERHEAD CATENARY EQUIPMENT.

6 Trains per Hour in Each Direction.					
6	**9**	**12**	**18**	**36**	*a*
6	4	3	2	1	*b*
4·5	6·75	9	13·5	27	*c*
53	79	105	158	315	*d*
210	315	420	630	1,260	*e*
3,530,000	5,300,000	7,050,000	10,600,000	21,200,000	*f*
3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	10 st. 17 run.	*g*
750	938	1,125	1,575	2,850	*h*
1,800	2,250	2,700	3,780	6,840	*i*
1,350	1,690	2,025	2,835	5,130	*j*
2×(2×340)	2×(2×420)	2×(2×500)	2×(2×700)	3×(2×850)	*k*
1,360	1,680	2,000	2,800	5,100	*l*
£6·85	£6·25	£5·8	£5·3	£4·8	*m*
£9,310	£10,500	£11,600	£14,850	£24,480	*n*
22·2	26·6	29·6	31·7	35·0	*o*
28	33·6	37·4	40·0	44·2	*p*
81·8	84·2	85·8	86·9	88·0	*q*
785,000	1,000,000	1,170,000	1,600,000	2,900,000	*r*
£465	£525	£580	£743	£1,224	*s*
£700	£710	£720	£740	£780	*t*
£47	£53	£58	£74	£122	*u*
£1,637	£2,082	£2,440	£3,340	£6,050	*v*
£2,849	£3,370	£3,798	£4,897	£8,176	*w*
0·194*d.*	0·153*d.*	0·129*d.*	0·111*d.*	0·093*d.*	*x*
0·694*d.*	0·653*d.*	0·629*d.*	0·611*d.*	0·593*d.*	*y*
8,160	6,720	6,000	5,600	5,100	*z*
£55,900	£42,100	£34,800	£29,970	£24,500	A
£17,094	£13,480	£11,394	£9,794	£8,176	B
0·125	0·188	0·25	0·375	0·75	C
0·34	0·228	0·17	0·114	0·057	D
1·092	1·135	1·164	1·242	1·46	E
5,310	12,280	22,250	53,700	250,500	F
37,170	85,960	155,750	375,900	1,753,500	G
1·05	1·62	2·21	3·54	8·25	H
£77	£179	£324	£781	£3,655	I
£462	£716	£972	£1,562	£3,655	J
£3,025	£3,138	£3,250	£3,475	£4,150	K
£109,000	£113,000	£117,000	£125,000	£149,500	L
£5,450	£5,650	£5,850	£6,250	£7,475	M
£3,270	£3,390	£3,510	£3,750	£4,485	N
£9,182	£9,756	£10,332	£11,562	£15,615	O
£26,276	£23,236	£21,726	£21,356	£23,791	P
£164,900	£155,100	£151,800	£154,970	£174,000	Q

TABLE III.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{2400 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 2400 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 200 amperes starting, 50 running .	..
i	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 2400}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units (2 rotaries in series per unit). . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete	From curves
n	,, sub-station	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . ohm	..
E	Resistance of conductor and track return from sub-station to neutral point . . . . ohm	$(\text{D} + 0{\cdot}024) \times \frac{a}{2}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$\text{F} \times 7000/1000$
H	Percentage conductor and track loss	$\text{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of track-equipment per mile of double track . . .	..
L	Total cost of track-equipment	$\text{K} \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$\text{L} \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$\text{L} \times \frac{3}{100}$
O	Total charges due to track	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and track charges	$\text{O} + \text{B}$
Q	,, capital cost of sub-stations and track-equipment .	$\text{A} + \text{L}$

2,400-Volt Overhead Catenary Equipment—*continued.*

12 Trains per Hour in Each Direction.					
6	**9**	**12**	**18**	**36**	*a*
6	4	3	2	1	*b*
9	13·5	18	27	54	*c*
105	158	210	315	630	*d*
420	630	840	1,260	2,520	*e*
7,050,000	10,600,000	14,100,000	21,200,000	42,400,000	*f*
4½ st. 4½ run.	6 st. 7½ run.	7½ st. 10½ run.	10 st. 17 run.	17 st. 37 run.	*g*
1,125	1,575	2,025	2,850	5,250	*h*
2,700	3,780	4,860	6,840	12,600	*i*
2,025	2,835	3,645	5,130	9,450	*j*
2×(2×500)	2×(2×700)	3×(2×600)	3×(2×850)	4×(2×1,200)	*k*
2,000	2,800	3,600	5,100	9,600	*l*
£5·8	£5·3	£5·2	£4·8	£4·5	*m*
£11,600	£14,850	£18,720	£24,480	£43,200	*n*
29·5	31·7	32·8	35·0	38·0	*o*
37·0	40·0	41·5	44·0	48·0	*p*
85·8	87·0	87·3	88·0	89·2	*q*
1,170,000	1,600,000	2,000,000	2,900,000	5,200,000	*r*
£580	£742	£936	£1,224	£2,160	*s*
£720	£740	£760	£780	£800	*t*
£58	£74	£94	£123	£216	*u*
£2,440	£3,340	£4,180	£6,050	£10,850	*v*
£3,798	£4,896	£5,970	£8,177	£14,026	*w*
0·129*d.*	0·111*d.*	0·105*d.*	0·093*d.*	0·080*d.*	*x*
0·629*d.*	0·611*d.*	0·605*d.*	0·593*d.*	0·580*d.*	*y*
12,000	11,200	10,800	10,200	9,600	*z*
£69,600	£59,400	£56,160	£48,960	£43,200	A
£22,788	£19,584	£17,910	£16,354	£14,026	B
0·25	0·375	0·5	0·75	1·5	C
0·170	0·114	0·085	0·057	0·028	D
0·582	0·621	0·654	0·729	0·936	E
11,120	26,900	50,000	125,300	645,000	F
77,840	188,300	350,000	877,100	4,515,000	G
1·1	1·77	2·5	4·15	10·6	H
£162	£392	£730	£1,825	£9,400	I
£972	£1,568	£2,190	£3,650	£9,400	J
£3,250	£3,475	£3,700	£4,150	£5,500	K
£117,000	£125,000	£133,000	£149,500	£198,000	L
£5,850	£6,250	£6,650	£7,475	£9,900	M
£3,520	£3,750	£4,000	£4,500	£5,950	N
£10,342	£11,568	£12,840	£15,625	£25,250	O
£33,130	£31,152	£30,750	£31,979	£39,276	P
£186,600	£184,400	£189,160	£198,460	£241,200	Q

TABLE III.—36-MILE DOUBLE-TRACK SUBURBAN RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$36/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 36 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{2400 \times 2}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum	$\left\{\frac{e \times 2400 \times 7000}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 200 amperes starting, 50 running .	..
	,, kilowatt demand per sub-station . . KW.	$\left\{\frac{h \times 2400}{1000}\right\}$
j	Half above increased by 50 per cent. for spare . . ,,	..
k	Sub-station units (2 rotaries in series per unit) . ,,	..
l	,, capacity . . . . ,,	..
m	Cost per kilowatt of sub-station complete	From curves
n	,, sub-station	$l \times m$
o	Sub-station load-factor (over 24 hours) . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Converter ,, (,, 19 ,,) . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KW.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of contact conductor . . . . . . sq. in.	..
D	Resistance of conductor per mile . . . . ohm	..
E	Resistance of conductor and track return from sub-station to neutral point . . . . ohm	$\left\{(D + 0{\cdot}024) \times \frac{a}{2}\right\}$
F	Average watts lost in four conductors and tracks . . .	$\left\{\frac{4 \times E \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station section per annum	$F \times 7000/1000$
H	Percentage conductor and track loss	$G/f \times 100$
I	Value of track loss at 0·5*d*. per unit	$G \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$I \times b$
K	Cost of track-equipment per mile of double track . . .	..
L	Total cost of track-equipment	$K \times 36$
M	Capital charge on track-equipment at 5 per cent. . . .	$L \times \frac{1}{20}$
N	Maintenance of track-equipment at 3 per cent. . . .	$L \times \frac{3}{100}$
O	Total charges due to track	$J + M + N$
P	,, sub-station and track charges	$O + B$
Q	,, capital cost of sub-stations and track-equipment .	$A + L$

2,400-Volt Overhead Catenary Equipment—*continued.*

24 Trains per Hour in Each Direction.					
4	**6**	**9**	**12**	**18**	*a*
9	6	4	3	2	*b*
12	18	27	36	54	*c*
140	210	315	420	630	*d*
560	840	1,260	1,680	2,520	*e*
9,400,000	14,100,000	21,200,000	28,200,000	42,400,000	*f*
5½ st. 6½ run.	7½ st. 10½ run.	10 st. 17 run.	13 st. 23 run.	18 st. 36 run.	*g*
1,425	2,025	2,850	3,750	5,400	*h*
3,420	4,860	6,840	9,000	13,000	*i*
2,560	3,640	5,130	6,750	9,750	*j*
2×(2×650)	2×(2×900)	2×(2×1,250)	3×(2×1,100)	4×(2×1,200)	*k*
2,600	3,600	5,000	6,600	9,600	*l*
£5·35	£4·8	£4·6	£4·65	£4·6	*m*
£13,900	£17,300	£23,000	£30,700	£44,200	*n*
31·1	32·8	35·0	35·5	37·0	*o*
39·3	41·5	44·3	44·8	46·7	*p*
86·6	87·6	88·5	88·5	89·0	*q*
1,460,000	2,000,000	2,800,000	3,650,000	5,300,000	*r*
£695	£865	£1,150	£1,535	£2,210	*s*
£740	£760	£780	£800	£820	*t*
£70	£86	£115	£154	£221	*u*
£3,040	£4,170	£5,840	£7,600	£11,040	*v*
£4,545	£5,881	£7,885	£10,089	£14,291	*w*
0·116*d.*	0·100*d.*	0·089*d.*	0·085*d.*	0·081*d.*	*x*
0·616*d.*	0·60*d.*	0·589*d.*	0·585*d.*	0·581*d.*	*y*
23,400	21,600	20,000	19,800	19,200	*z*
£125,100	£103,800	£92,000	£92,000	£88,400	A
£40,905	£35,286	£31,540	£30,262	£28,582	B
0·35	0·5	0·75	1·0	1·5	C
0·121	0·085	0·057	0·042	0·028	D
0·29	0·327	0·364	0·396	0·468	E
9,840	24,950	62,600	121,000	322,000	F
68,880	174,650	438,200	847,000	2,254,000	G
0·73	1·24	2·07	3·0	5·31	H
£144	£364	£914	£1,765	£4,700	I
£1,296	£2,084	£3,656	£5,295	£9,400	J
£3,430	£3,700	£4,150	£4,600	£5,500	K
£123,500	£133,000	£149,500	£165,500	£198,000	L
£6,175	£6,650	£7,475	£8,275	£9,900	M
£3,705	£4,000	£4,500	£4,965	£5,950	N
£11,176	£12,734	£15,631	£18,535	£25,250	O
£52,081	£48,020	£47,171	£48,797	£53,832	P
£248,600	£236,800	£241,500	£257,500	£286,400	Q

TABLE IV.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0{\cdot}8}$
e	Total average amperes per sub-station	$d \times 4$
f	,, output per sub-station per annum.	$\left\{\frac{e \times 5000 \times 7000 \times 0{\cdot}8}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 192 amperes starting, 30 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 5000}{1000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station.	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity. . . . . KVA.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance per mile of track . . . . ohm	..
E	Resistance of conductor and track return	$(\mathrm{D} + 0{\cdot}168) \times \frac{a}{2}$
F	Average watts lost in four tracks and conductors . . .	$\left\{\frac{4 \times \mathrm{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station per annum	$\mathrm{F} \times 7000/1000$
H	Track loss per cent.	$\mathrm{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit	$\mathrm{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\mathrm{I} \times b$
K	Cost overhead structure and bonding per mile double-track	..
L	Total capital cost of track-equipment	$\mathrm{K} \times 72$
M	Capital charge at 5 per cent.	$\mathrm{L} \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$\mathrm{L} \times \frac{3}{100}$
O	Total charges due to conducting system.	$\mathrm{J} + \mathrm{M} + \mathrm{N}$
P	,, sub-station and conductor charges	$\mathrm{O} + \mathrm{B}$
Q	,, capital expended on sub-stations and track . . .	$\mathrm{A} + \mathrm{L}$

5,000 VOLTS, SINGLE-PHASE.

2 Trains per Hour.				
12	**18**	**24**	**36**	*a*
6	4	3	2	*b*
3	4·5	6	9	*c*
21·3	32	43	64	*d*
85	128	172	256	*e*
2,350,000	3,525,000	4,700,000	7,066,000	*f*
3 starting	3½ st. 1 run.	4 st. 2 run.	4½ st. 4½ run.	*g*
576	702	828	999	*h*
2,880	3,510	4,140	4,995	*i*
2,160	2,630	3,105	3,750	*j*
2×1,000	2×1,250	2×1,500	3×1,250	*k*
2,000	2,500	3,000	3,750	*l*
£2·5	£2·25	£2·1	£1·9	*m*
£5,000	£5,625	£6,300	£7,125	*n*
11·7	14·4	16·5	20·3	*o*
14·8	18·2	20·8	25·6	*p*
93·0	94·2	95·0	95·8	*q*
178,000	215,000	250,000	310,000	*r*
£250	£281	£315	£357	*s*
£690	£700	£710	£720	*t*
£25	£28	£32	£36	*u*
£371	£448	£521	£646	*v*
£1,336	£1,457	£1,578	£1,759	*w*
0·136*d.*	0·099*d.*	0·081*d.*	0·059*d.*	*x*
0·636*d.*	0·599*d.*	0·581*d.*	0·559*d.*	*y*
12,000	10,000	9,000	7,500	*z*
£30,000	£22,500	£18,900	£14,250	A
£8,016	£5,828	£4,734	£3,518	B
0·166	0·166	0·166	0·188	C
0·256	0·256	0·256	0·228	D
2·55	3·82	5·09	7·14	E
2,010	6,780	16,320	50,700	F
14,070	47,360	114,240	354,900	G
0·60	1·34	2·42	5·02	H
£29	£98	£238	£740	I
£174	£392	£714	£1,480	J
£3,350	£3,350	£3,350	£3,390	K
£241,000	£241,000	£241,000	£244,000	L
£12,050	£12,050	£12,050	£12,200	M
£7,230	£7,230	£7,230	£7,320	N
£19,454	£19,672	£19,995	£21,000	O
£27,470	£25,500	£24,729	£24,518	P
£271,000	£263,500	£259,900	£258,250	Q

TABLE IV.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0\cdot8}$
e	Total average amperes per sub-station	$d \times 4$
f	,, output per sub-station per annum.	$\left\{\frac{e \times 5000 \times 7000 \times 0\cdot8}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 192 amperes starting, 30 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 5000}{1000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-stations. . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0\cdot5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0\cdot5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance per mile of track . . . . ohm	..
E	Resistance of conductor and track return	$\left\{(\text{D} + 0\cdot168) \times \frac{a}{2}\right\}$
F	Average watts lost in four tracks and conductors . . .	$\left\{\frac{4 \times \text{E} \times d^2 \times 1\cdot3}{3}\right\}$
G	Units lost per sub-station per annum	$\text{F} \times 7000/1000$
H	Track loss per cent.	$\text{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit.	$\text{G} \times 0\cdot5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost overhead structure and bonding per mile double-track	..
L	Total capital cost of track-equipment	$\text{K} \times 72$
M	Capital charge at 5 per cent.	$\text{L} \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$\text{L} \times \frac{3}{100}$
O	Total charges due to conducting system	$\text{J} + \text{M} + \text{N}$
P	,, sub-station and conductor charges	$\text{O} + \text{B}$
Q	,, capital expended on sub-stations and track . . .	$\text{A} + \text{L}$

5,000 Volts, Single-Phase—*continued.*

3 Trains per Hour.					
9	12	18	24	36	*a*
8	6	4	3	2	*b*
3·38	4·5	6·75	9	13·5	*c*
24	32	48	64	96	*d*
96	128	192	256	384	*e*
2,650,000	3,525,000	5,300,000	7,050,000	10,600,000	*f*
3·38 starting	3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	*g*
649	702	850	999	1,377	*h*
3,245	3,510	4,250	4,995	6,885	*i*
2,435	2,630	3,185	3,745	5,163	*j*
2×1,200	2×1,250	2×1,500	3×1,250	3×1,750	*k*
2,400	2,500	3,000	3,750	5,250	*l*
£2·3	£2·25	£2·1	£1·9	£1·65	*m*
£5,520	£5,625	£6,300	£7,125	£8,663	*n*
11·7	14·4	17·9	20·3	22·1	*o*
14·8	18·3	22·6	25·6	28·0	*p*
93·0	94·3	95·2	95·8	96·0	*q*
200,000	210,000	270,000	310,000	440,000	*r*
£276	£281	£315	£356	£433	*s*
£700	£710	£720	£730	£740	*t*
£28	£28	£32	£36	£43	*u*
£417	£438	£563	£646	£916	*v*
£1,421	£1,457	£1,630	£1,768	£2,132	*w*
0·128*d.*	0·120*d.*	0·074*d.*	0·060*d.*	0·048*d.*	*x*
0·628*d.*	0·620*d.*	0·574*d.*	0·560*d.*	0·548*d.*	*y*
19,200	15,000	12,000	11,250	10,500	*z*
£44,200	£33,750	£25,200	£21,400	£17,350	A
£11,368	£8,742	£6,520	£5,304	£4,264	B
0·166	0·166	0·166	0·188	0·25	C
0·256	0·256	0·256	0·228	0·17	D
1·91	2·55	3·82	4·75	6·08	E
1,905	4,530	15,250	33,750	97,200	F
13,335	31,710	106,750	236,250	680,400	G
0·51	0·90	2·01	3·36	6·42	H
£28	£66	£222	£493	£1,420	I
£224	£396	£888	£1,479	£2,840	J
£3,350	£3,350	£3,350	£3,390	£3,500	K
£241,000	£241,000	£241,000	£244,000	£252,000	L
£12,050	£12,050	£12,050	£12,200	£12,600	M
£7,230	£7,230	£7,230	£7,320	£7,560	N
£19,504	£19,676	£20,168	£20,999	£23,000	O
£30,872	£28,418	£26,688	£26,303	£27,264	P
£285,200	£274,750	£266,200	£265,400	£269,350	Q

TABLE IV.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	„ amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0{\cdot}8}$
e	Total average amperes per sub-station	$d \times 4$
f	„ output per sub-station per annum	$\left\{\frac{e \times 5000 \times 7000 \times 0{\cdot}8}{1000}\right\}$
g	Demand per sub-station	..
h	Maximum amperes at 192 amperes starting, 30 running .	..
i	„ KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 5000}{1000}\right\}$
j	Half this increased by 50 per cent. for spare . . „	..
k	Sub-station units . . . . „	..
l	Total sub-station capacity. . . . . „	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer „ (19 „) . . . . . „	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . „	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5d. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	„ capital cost of all sub-stations	$z \times m$
B	„ cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance per mile of track . . . . ohm	..
E	Resistance of conductor and track return	$(D + 0{\cdot}168) \times \frac{a}{2}$
F	Average watts lost in four tracks and conductors . . .	$\left\{\frac{4 \times E \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station per annum	$F \times 7000/1000$
H	Track loss per cent.	$G/f \times 100$
I	Value of track loss at 0·5d. per unit	$G \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$I \times b$
K	Cost overhead structure and bonding per mile double-track	..
L	Total capital cost of track-equipment	$K \times 72$
M	Capital charge at 5 per cent.	$L \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$L \times \frac{3}{100}$
O	Total charges due to conducting system.	$J + M + N$
P	„ sub-station and conductor charges	$O + B$
Q	„ capital expended on sub-stations and track . . .	$A + L$

5,000 VOLTS, SINGLE-PHASE—*continued.*

6 Trains per Hour.					
9	**12**	**18**	**24**	**36**	*a*
8	6	4	3	2	*b*
6·75	9	13·5	18	27	*c*
48	64	96	128	192	*d*
192	256	384	512	768	*e*
5,350,000	7,050,000	10,600,000	14,100,000	21,200,000	*f*
4 st. 2¾ run.	4½ st. 4⅓ run.	6 st. 7½ run.	7½ st. 10½ run.	10 st. 17 run.	*g*
850	999	1,377	1,755	2,430	*h*
4,250	4,995	6,885	8,775	12,150	*i*
3,190	3,745	5,165	6,580	9,170	*j*
2×1,500	3×1,250	3×1,750	3×2,200	3×3,000	*k*
3,000	3,750	5,250	6,600	9,000	*l*
£2·1	£1·9	£1·65	£1·6	£1·5	*m*
£6,300	£7,125	£8,663	£10,560	£13,500	*n*
17·9	20·3	22·1	23·0	25·0	*o*
22·6	25·6	28·0	29·1	31·6	*p*
95·2	95·8	96·0	96·2	96·5	*q*
270,000	310,000	440,000	570,000	800,000	*r*
£315	£356	£433	£528	£675	*s*
£710	£720	£730	£740	£750	*t*
£32	£36	£43	£53	£68	*u*
£563	£646	£916	£1,188	£1,668	*v*
£1,620	£1,758	£2,122	£2,509	£3,161	*w*
0·072*d.*	0·060*d.*	0·048*d.*	0·043*d.*	0·036*d.*	*x*
0·572*d.*	0·560*d.*	0·548*d.*	0·543*d.*	0·536*d.*	*y*
24,000	22,500	21,000	19,800	18,000	*z*
£50,400	£42,800	£34,650	£31,700	£27,000	A
£12,960	£10,748	£8,488	£7,527	£6,322	B
0·166	0·188	0·25	0·375	0·5	C
0·256	0·228	0·17	0·114	0·085	D
1·91	2·38	3·04	3·38	4·55	E
7,630	16,900	48,600	96,000	291,000	F
53,410	118,300	340,200	672,000	2,037,000	G
1·00	1·68	3·21	4·77	9·60	H
£111	£246	£709	£1,400	£4,240	I
£888	£1,576	£2,836	£4,200	£8,480	J
£3,350	£3,390	£3,500	£3,730	£3,950	K
£241,000	£244,000	£252,000	£268,500	£284,500	L
£12,050	£12,200	£12,600	£13,425	£14,225	M
£7,230	£7,320	£7,560	£8,060	£8,540	N
£20,168	£21,096	£22,996	£25,625	£31,245	O
£33,128	£31,844	£31,484	£33,152	£37,567	P
£291,400	£286,800	£286,650	£300,200	£311,500	Q

TABLE V.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{10,000 \times 2 \times 0\cdot8}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum.	$\frac{e \times 10,000 \times 7000 \times 0\cdot08}{1,000}$
g	Demand per sub-station	..
h	Maximum demand at 96 amperes starting, 15 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 10,000}{1,000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0\cdot5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0\cdot5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor	..
D	Resistance per mile of track	..
E	,, of conductor and track return	$(D + 0\cdot168)\ a/2$
F	Average watts lost in four tracks and conductors . . .	$\left\{\frac{4 \times E \times d^2 \times 1\cdot3}{3}\right\}$
G	Units lost per sub-station per annum	$F \times 7,000/1,000$
H	Track loss . . . . per cent.	$G/f \times 100$
I	Value of track loss at 0·5*d*. per unit	$G \times 0\cdot5/240$
J	Total value of track loss for whole line	$I \times b$
K	{Cost of overhead structure and bonding per mile double track . . . .}	..
L	Total capital cost of overhead structure	$K \times 72$
M	Capital charge at 5 per cent.	$L \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$L \times \frac{3}{100}$
O	Total charges due to conducting system.	$J + M + N$
P	,, sub-station and conductor charges.	$O + B$
Q	,, capital expended on sub-stations and track . . .	$A + L$

10,000 Volts, Single-Phase.

2 Trains per Hour.				
18	24	36	72	*a*
4	3	2	1	*b*
4·5	6	9	18	*c*
16	21·3	32	64	*d*
64	85	128	256	*e*
3,525,000	4,700,000	7,066,000	14,132,000	*f*
3½ st. 1 run.	4 st. 2 run.	4½ st. 4½ run.	7½ st. 10½ run.	*g*
351	414	500	878	*h*
3,510	4,140	5,000	8,780	*i*
2,630	3,100	3,750	6,580	*j*
2×1,300	2×1,550	2×1,850	3×2,200	*k*
2,600	3,100	3,700	6,600	*l*
£2·22	£2·05	£1·9	£1·6	*m*
£5,770	£6,360	£7,040	£10,550	*n*
14·4	16·2	20·4	23·1	*o*
18·2	20·5	25·6	29·2	*p*
94·3	95	95·8	96·3	*q*
215,000	250,000	304,000	538,000	*r*
£289	£318	£352	£528	*s*
£700	£710	£720	£730	*t*
£29	£32	£35	£53	*u*
£448	£521	£633	£1,120	*v*
£1,466	£1,581	£1,740	£2,431	*w*
0·100*d.*	0·081*d.*	0·059*d.*	0·041*d.*	*x*
0·600*d.*	0·581*d.*	0·559*d.*	0·541*d.*	*y*
10,400	9,300	7,400	6,600	*z*
£23,100	£19,100	£14,050	£10,550	A
£5,864	£4,743	£3,480	£2,431	B
0·166	0·166	0·166	0·188	C
0·256	0·256	0·256	0·228	D
3·82	5·09	7·63	14·25	E
1,700	4,000	13,570	112,000	F
11,900	28,000	94,990	784,000	G
0·34	0·60	1·35	5·55	H
£25	£58	£198	£1,630	I
£100	£174	£396	£1,630	J
£3,750	£3,750	£3,750	£3,790	K
£270,000	£270,000	£270,000	£273,000	L
£13,500	£13,500	£13,500	£13,650	M
£8,100	£8,100	£8,100	£8,180	N
£21,700	£21,774	£21,996	£23,460	O
£27,564	£26,517	£25,476	£25,891	P
£293,100	£289,100	£284,050	£283,550	Q

G 2

TABLE V.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{10,000 \times 2 \times 0 \cdot 8}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum.	$\frac{e \times 10,000 \times 7000 \times 0 \cdot 08}{1,000}$
g	Demand per sub-station	..
h	Maximum demand at 96 amperes starting, 15 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\frac{h \times 10,000}{1,000}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\frac{e}{h} \times \frac{19}{24} \times 100$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0 \cdot 5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0 \cdot 5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor	..
D	Resistance per mile of track	..
E	,, of conductor and track return	$(D + 0 \cdot 168)\ a/2$
F	Average watts lost in four tracks and conductors . . .	$\frac{4 \times E \times d^2 \times 1 \cdot 3}{3}$
G	Units lost per sub-station per annum	$F \times 7,000/1,000$
H	Track loss . . . . per cent.	$G/f \times 100$
I	Value of track loss at 0·5*d*. per unit	$G \times 0 \cdot 5/240$
J	Total value of track loss for whole line	$I \times b$
K	Cost of overhead structure and bonding per mile double track	..
L	Total capital cost of overhead structure	$K \times 72$
M	Capital charge at 5 per cent.	$L \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$L \times \frac{3}{100}$
O	Total charges due to conducting system.	$J + M + N$
P	,, sub-station and conductor charges.	$O + B$
Q	,, capital expended on sub-stations and track . . .	$A + L$

10,000 Volts, Single-Phase—*continued*.

3 Trains per Hour.					
12	18	24	36	72	*a*
6	4	3	2	1	*b*
4·5	6·75	9	13·5	27	*c*
16	24	32	48	96	*d*
64	96	128	192	384	*e*
3,525,000	5,300,000	7,050,000	10,600,000	21,200,000	*f*
3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	10 st. 17 run.	*g*
351	426	500	689	1,215	*h*
3,510	4,260	5,000	6,890	12,150	*i*
2,630	3,190	3,750	5,170	9,100	*j*
2 × 1,300	2 × 1,600	2 × 1,850	3 × 1,750	3 × 3,000	*k*
2,600	3,200	3,700	5,250	9,000	*l*
£2·22	£2·02	£1·9	£1·7	£1·52	*m*
£5,770	£6,460	£7,040	£8,920	£13,700	*n*
14·4	17·9	20·4	22	25	*o*
18·2	22·6	25·6	27·9	31·6	*p*
94·3	95·3	95·8	96·0	96·5	*q*
215,000	260,000	300,000	450,000	800,000	*r*
£289	£323	£352	£446	£685	*s*
£700	£710	£720	£730	£740	*t*
£35	£32	£35	£45	£68	*u*
£448	£542	£625	£937	£1,668	*v*
£1,472	£1,607	£1,732	£2,158	£3,161	*w*
0·100*d.*	0·073*d.*	0·059*d.*	0·049*d.*	0·036*d.*	*x*
0·600*d.*	0·573*d.*	0·559*d.*	0·549*d.*	0·536*d.*	*y*
15,600	12,800	11,100	10,500	9,000	*z*
£34,600	£25,800	£21,100	£17,850	£13,700	A
£8,832	£6,428	£5,196	£4,316	£3,161	B
0·166	0·166	0·166	0·166	0·25	C
0·256	0·256	0·256	0·256	0·17	D
2·55	3·82	5·09	7·63	12·18	E
1,130	3,820	9,040	30,500	194,500	F
7,910	26,740	63,280	213,500	1,361,500	G
0·22	0·50	0·89	2·01	6·42	H
£17	£56	£132	£445	£2,840	I
£102	£224	£396	£890	£2,840	J
£3,750	£3,750	£3,750	£3,750	£3,900	K
£270,000	£270,000	£270,000	£270,000	£281,000	L
£13,500	£13,500	£13,500	£13,500	£14,050	M
£8,100	£8,100	£8,100	£8,100	£8,430	N
£21,702	£21,824	£21,996	£22,490	£25,320	O
£30,534	£28,352	£27,192	£26,806	£28,481	P
£304,600	£295,800	£291,100	£287,850	£294,700	Q

TABLE V.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes in conductor at sub-station	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{10{,}000 \times 2 \times 0{\cdot}08}$
e	Total average amperes per sub-station (19 hours) . . .	$d \times 4$
f	,, output per sub-station per annum.	$\frac{e \times 10{,}000 \times 7000 \times 0{\cdot}08}{1{,}000}$
g	Demand per sub-station	..
h	Maximum demand at 96 amperes starting, 15 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 10{,}000}{1{,}000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity. . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of all sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor	..
D	Resistance per mile of track	..
E	,, of conductor and track return	$(\mathrm{D} + 0{\cdot}168)\ a/2$
F	Average watts lost in four tracks and conductors . . .	$\left\{\frac{4 \times \mathrm{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station per annum	$\mathrm{F} \times 7{,}000/1{,}000$
H	Track loss . . . . per cent.	$\mathrm{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit.	$\mathrm{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\mathrm{I} \times b$
K	Cost of overhead structure and bonding per mile double track	..
L	Total capital cost of overhead structure	$\mathrm{K} \times 72$
M	Capital charge at 5 per cent.	$\mathrm{L} \times \frac{1}{20}$
N	Maintenance at 3 per cent.	$\mathrm{L} \times \frac{3}{100}$
O	Total charges due to conducting system	$\mathrm{J} + \mathrm{M} + \mathrm{N}$
P	,, sub-station and conductor charges.	$\mathrm{O} + \mathrm{B}$
Q	,, capital expended on sub-stations and track . . .	$\mathrm{A} + \mathrm{L}$

10,000 Volts, Single-Phase—*continued.*

6 Trains per hour.					
9	**12**	**18**	**24**	**36**	*a*
8	6	4	3	2	*b*
6·75	9	13·5	18	27	*c*
24	32	48	64	96	*d*
96	128	192	256	384	*e*
5,300,000	7,050,000	10,600,000	14,100,000	21,200,000	*f*
4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	7½ st. 10½ run.	10 st. 17 run.	*g*
426	500	689	878	1,215	*h*
4,260	5,000	6,890	8,780	12,150	*i*
3,190	3,750	5,170	6,580	9,100	*j*
2×1,600	2×1,850	3×1,750	3×2,200	3×3,000	*k*
3,200	3,700	5,250	6,600	9,000	*l*
£2·02	£1·9	£1·7	£1·6	£1·52	*m*
£6,460	£7,040	£8,920	£10,550	£13,700	*n*
17·9	20·4	22	23·1	25	*o*
22·6	25·6	27·9	29·2	31·6	*p*
95·3	95·8	96·0	96·3	96·5	*q*
260,000	300,000	450,000	538,000	800,000	*r*
£323	£352	£446	£528	£685	*s*
£700	£710	£720	£730	£740	*t*
£32	£35	£45	£53	£68	*u*
£542	£625	£937	£1,120	£1,668	*v*
£1,597	£1,722	£2,148	£2,431	£3,161	*w*
0·072*d.*	0·058*d.*	0·049*d.*	0·041*d.*	0·036*d.*	*x*
0·572*d.*	0·558*d.*	0·549*d.*	0·541*d.*	0·536*d.*	*y*
25,600	22,200	21,000	19,800	18,000	*z*
£51,700	£42,240	£35,680	£31,650	£27,400	A
£12,776	£10,332	£8,592	£7,293	£6,362	B
0·166	0·166	0·166	0·188	0·25	C
0·256	0·256	0·256	0·228	0·17	D
1·91	2·55	3·82	4·75	6·08	E
1,905	4,520	15,250	33,750	97,100	F
13,335	31,640	106,750	236,250	679,700	G
0·25	0·45	1·05	1·67	3·20	H
£28	£66	£222	£492	£1,410	I
£224	£396	£888	£1,476	£2,820	J
£3,750	£3,750	£3,750	£3,790	£3,900	K
£270,000	£270,000	£270,000	£273,000	£281,000	L
£13,500	£13,500	£13,500	£13,650	£14,050	M
£8,100	£8,100	£8,100	£8,180	£8,430	N
£21,824	£21,996	£22,488	£23,306	£25,300	O
£34,600	£32,328	£31,080	£30,599	£31,662	P
£321,700	£312,240	£305,680	£304,650	£308,400	Q

TABLE VI.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\dfrac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes per phase in conductor at sub-station .	$\dfrac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0{\cdot}9 \times \sqrt{3}}$
e	Total average amperes per phase per sub-station . . .	$d \times 4$
f	,, output per sub-station per annum.	$\dfrac{e \times 5000 \times 7000 \times 0{\cdot}9 \times \sqrt{3}}{1000}$
g	Demand per sub-station	..
h	Maximum demand at 74 amperes starting, 16 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\dfrac{h \times 5000 \times \sqrt{3}}{1000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curve
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\left\{\dfrac{e}{h} \times \dfrac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \dfrac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance of one conductor to half-way point	Res. per mile $\times\ a/2$
D[1]	,, track rails to half-way point	$0{\cdot}168 \times a/2$
E	Total resistance in three phases	$(2\,\text{D} + \text{D}^1)$
F	Average watts lost in four tracks	$\left\{\dfrac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station per annum	$\text{F} \times 7000/1000$
H	Track loss . . . . per cent.	$\text{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit.	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of overhead structure and track bonding per mile of double track	..
L	Total capital cost of track-equipment	$\text{K} \times 72$
M	Capital charge at 5 per cent.	$\text{L} \times \frac{1}{20}$
N	Maintenance ,, 3 ,, ...	$\text{L} \times \frac{3}{100}$
O	Total charges due to conducting system	$\text{J} + \text{M} + \text{N}$
P	,, of sub-station and conductor charges	$\text{O} + \text{B}$
Q	,, capital expended on sub-stations and track-equipment	$\text{A} + \text{L}$

5,000 Volts, Three-Phase.

2 Trains per Hour.				
12	18	24	36	*a*
6	4	3	2	*b*
3	4·5	6	9	*c*
11	16·4	22·1	32·9	*d*
44	65·6	88·4	131·6	*e*
2,350,000	3,525,000	4,700,000	7,066,000	*f*
3 starting	3½ st. 1 run.	4 st. 2 run.	4½ st. 4½ run.	*g*
222	275	328	405	*h*
1,925	2,385	2,840	3,510	*i*
1,440	1,790	2,130	2,630	*j*
2×750	2×900	2×1,100	2×1,300	*k*
1,500	1,800	2,200	2,600	*l*
£2·7	£2·55	£2·37	£2·22	*m*
£4,050	£4,585	£5,210	£5,770	*n*
15·7	18·9	21·3	26·8	*o*
19·8	23·9	27·0	32·5	*p*
94·7	95·5	96·0	96·6	*q*
130,000	170,000	200,000	250,000	*r*
£202	£229	£260	£289	*s*
£690	£700	£710	£720	*t*
£20	£23	£26	£29	*u*
£271	£354	£417	£521	*v*
£1,183	£1,306	£1,413	£1,559	*w*
0·120*d.*	0·089*d.*	0·072*d.*	0·053*d.*	*x*
0·620*d.*	0·589*d.*	0·572*d.*	0·553*d.*	*y*
9,000	7,200	6,600	5,200	*z*
£24,300	£19,340	£15,630	£11,540	A
£7,098	£5,224	£4,239	£3,118	B
0·166	0·166	0·166	0·166	C
1·535	2·305	3·075	4·610	D
1·010	1·510	2·018	3·025	D'
4·080	6·120	8·168	12·245	E
855	2,860	6,920	23,000	F
5,985	20,020	48,440	161,000	G
0·25	0·57	1·03	2·28	H
£12·5	£41·8	£101	£336	I
£75	£167	£303	£672	J
£4,350	£4,350	£4,350	£4,350	K
£313,000	£313,000	£313,000	£313,000	L
£15,650	£15,650	£15,650	£15,650	M
£9,400	£9,400	£9,400	£9,400	N
£25,125	£25,217	£25,353	£25,722	O
£32,223	£30,441	£29,592	£28,840	P
£337,300	£332,340	£328,630	£324,640	Q

TABLE VI.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes per phase in conductor at sub-station .	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0{\cdot}9 \times \sqrt{3}}$
e	Total average amperes per phase per sub-station . . .	$d \times 4$
f	,, output per sub-station per annum.	$\frac{e \times 5000 \times 7000 \times 0{\cdot}9 \times \sqrt{3}}{1000}$
g	Demand per sub-station	..
h	Maximum demand at 74 amperes starting, 16 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\left\{\frac{h \times 5000 \times \sqrt{3}}{1000}\right\}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curves
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . . per cent.	$\left\{\frac{e}{h} \times \frac{19}{24} \times 100\right\}$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5*d*. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance of one conductor to half-way point	Res. per mile $\times a/2$
D[1]	,, track rails to half-way point	$0{\cdot}168 \times a/2$
E	Total resistance in three phases	$(2\,\text{D} + \text{D}^1)$
F	Average watts lost in four tracks	$\left\{\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}\right\}$
G	Units lost per sub-station per annum	$\text{F} \times 7000/1000$
H	Track loss . . . . per cent.	$\text{G}/f \times 100$
I	Value of track loss at 0·5*d*. per unit.	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of overhead structure and track bonding per mile of double track	..
L	Total capital cost of track-equipment	$\text{K} \times 72$
M	Capital charge at 5 per cent.	$\text{L} \times \frac{1}{20}$
N	Maintenance ,, 3 ,, ...	$\text{L} \times \frac{3}{100}$
O	Total charges due to conducting system	$\text{J} + \text{M} + \text{N}$
P	,, of sub-station and conductor charges	$\text{O} + \text{B}$
Q	,, capital expended on sub-stations and track-equipment	$\text{A} + \text{L}$

5,000 VOLTS, THREE-PHASE—*continued.*

3 Trains per Hour.					
9	12	18	24	36	*a*
8	6	4	3	2	*b*
3·38	4·5	6·75	9	13·5	*c*
12·3	16·4	24·6	32·9	49·3	*d*
49·2	65·6	98·4	131·6	197·2	*e*
2,650,000	3,525,000	5,300,000	7,050,000	10,600,000	*f*
3·38 starting	3½ st. 1 run.	4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	*g*
250	275	340	405	564	*h*
2,165	2,385	2,950	3,510	4,880	*i*
1,625	1,790	2,210	2,630	3,660	*j*
2×800	2×900	2×1,100	2×1,300	3×1,200	*k*
1,600	1,800	2,200	2,600	3,600	*l*
£2·67	£2·55	£2·37	£2·22	£1·95	*m*
£4,270	£4,585	£5,210	£5,770	£7,020	*n*
15·6	18·9	22·9	26·8	27·6	*o*
19·7	23·9	29·0	32·5	35·0	*p*
94·7	95·5	96·3	96·6	96·7	*q*
150,000	170,000	200,000	250,000	370,000	*r*
£214	£229	£260	£289	£351	*s*
£700	£710	£720	£730	£740	*t*
£21	£23	£26	£29	£35	*u*
£312	£354	£417	£521	£771	*v*
£1,247	£1,316	£1,423	£1,569	£1,897	*w*
0·113*d.*	0·089*d.*	0·064*d.*	0·054*d.*	0·043*d.*	*x*
0·613*d.*	0·589*d.*	0·564*d.*	0·554*d.*	0·543*d.*	*y*
12,800	10,800	8,800	7,800	7,200	*z*
£34,160	£27,510	£20,840	£17,310	£14,040	A
£9,976	£7,896	£5,692	£4,707	£3,794	B
0·166	0·166	0·166	0·166	0·166	C
1·151	1·535	2·305	3·075	4·610	D
0·756	1·010	1·510	2·018	3·025	D[1]
3·058	4·080	6·120	8·168	12·245	E
802	1,900	6,420	15,350	51,600	F
5,614	13,300	44,940	107,450	360,200	G
0·21	0·38	0·85	1·52	3·41	H
£11·7	£27·7	£94	£224	£753	I
£94	£166	£376	£672	£1,506	J
£4,350	£4,350	£4,350	£4,350	£4,350	K
£313,000	£313,000	£313,000	£313,000	£313,000	L
£15,650	£15,650	£15,650	£15,650	£15,650	M
£9,400	£9,400	£9,400	£9,400	£9,400	N
£25,144	£25,216	£25,426	£25,722	£26,556	O
£35,120	£33,112	£31,118	£30,429	£30,350	P
£347,160	£340,510	£333,840	£330,310	£327,040	Q

TABLE VI.—72-MILE DOUBLE-TRACK RAILWAY,

a	Distance between sub-stations . . . . miles	..
b	Number of sub-stations	$72/a$
c	Average number of trains per sub-station	$\frac{\text{trs./hr.} \times 72 \times 2}{\text{schedule speed} \times b}$
d	,, amperes per phase in conductor at sub-station .	$\frac{70 \times 100 \times \text{trs./hr.} \times a}{5000 \times 2 \times 0{\cdot}9 \times \sqrt{3}}$
e	Total average amperes per phase per sub-station . . .	$d \times 4$
f	,, output per sub-station per annum.	$\frac{e \times 5000 \times 7000 \times 0{\cdot}9 \times \sqrt{3}}{1000}$
g	Demand per sub-station	..
h	Maximum demand at 74 amperes starting, 16 running .	..
i	,, KVA. demand per sub-station . . . KVA.	$\frac{h \times 5000 \times \sqrt{3}}{1000}$
j	Half this increased by 50 per cent. for spare . . ,,	..
k	Sub-station units . . . . ,,	..
l	Total sub-station capacity . . . . ,,	..
m	Cost per KVA. of sub-station complete	From curve
n	Total cost per sub-station	$l \times m$
o	Sub-station load-factor (24 hours) . . . . per cent.	$\frac{e}{h} \times \frac{19}{24} \times 100$
p	Transformer ,, (19 ,,) . . . . . ,,	$e/h \times 100$
q	Annual overall efficiency of sub-station . . . ,,	From curves
r	Units lost per annum in sub-station	$\left(f \times \frac{100}{q}\right) - f$
s	Capital charge per sub-station at 5 per cent.	$n \times \frac{1}{20}$
t	Wages, superintendence, and stores	..
u	Repairs and renewals at 0·5 per cent.	$n \times \frac{1}{200}$
v	Cost of lost units at 0·5d. per unit	$r \times 0{\cdot}5/240$
w	Total cost of running sub-stations, including capital charge	$s + t + u + v$
x	Sub-station charge per unit delivered	$w \times 240/f$
y	Current cost per unit delivered	$0{\cdot}5 + x$
z	Total sub-station capacity . . . . KVA.	$l \times b$
A	,, capital cost of sub-stations	$z \times m$
B	,, cost of running all sub-stations	$w \times b$
C	Copper section of conductor . . . . sq. in.	..
D	Resistance of one conductor to half-way point	Res. per mile $\times a/2$
D[1]	,, track rails to half-way point	$0{\cdot}168 \times a/2$
E	Total resistance in three phases	$(2\,\text{D} + \text{D}^1)$
F	Average watts lost in four tracks	$\frac{4 \times \text{E} \times d^2 \times 1{\cdot}3}{3}$
G	Units lost per sub-station per annum	$\text{F} \times 7000/1000$
H	Track loss . . . . per cent.	$\text{G}/f \times 100$
I	Value of track loss at 0·5d. per unit.	$\text{G} \times 0{\cdot}5/240$
J	Total value of track loss for whole line	$\text{I} \times b$
K	Cost of overhead structure and track bonding per mile of double track	..
L	Total capital cost of track-equipment	$\text{K} \times 72$
M	Capital charge at 5 per cent.	$\text{L} \times \frac{1}{20}$
N	Maintenance ,, 3 ,, ...	$\text{L} \times \frac{3}{100}$
O	Total charges due to conducting system	$\text{J} + \text{M} + \text{N}$
P	,, of sub-station and conductor charges	$\text{O} + \text{B}$
Q	,, capital expended on sub-stations and track-equipment	$\text{A} + \text{L}$

5,000 VOLTS, THREE-PHASE—*continued.*

6 Trains per Hour.					
9	12	18	24	36	*a*
8	6	4	3	2	*b*
6·75	9	13·5	18	27	*c*
24·6	32·9	49·3	65·7	98·5	*d*
98·4	131·6	197·2	262·8	394·0	*e*
5,350,000	7,050,000	10,600,000	14,100,000	21,200,000	*f*
4 st. 2¾ run.	4½ st. 4½ run.	6 st. 7½ run.	7½ st. 10½ run.	10 st. 17 run.	*g*
340	405	564	723	1,012	*h*
2,950	3,510	4,880	6,260	8,770	*i*
2,210	2,630	3,670	4,700	6,570	*j*
2×1,100	2×1,300	3×1,250	4×1,175	4×1,640	*k*
2,200	2,600	3,750	4,700	6,560	*l*
£2·37	£2·22	£1·95	£1·75	£1·6	*m*
£5,210	£5,770	£7,320	£8,220	£10,500	*n*
22·9	26·8	27·6	28·8	30·8	*o*
29·0	32·5	35·0	36·4	39·0	*p*
96·3	96·6	96·7	96·8	97·0	*q*
200,000	250,000	370,000	470,000	650,000	*r*
£260	£289	£366	£413	£525	*s*
£710	£720	£730	£740	£750	*t*
£26	£29	£37	£41	£52	*u*
£417	£521	£771	£980	£1,355	*v*
£1,413	£1,559	£1,904	£2,174	£2,682	*w*
0·063*d.*	0·053*d.*	0·043*d.*	0·037*d.*	0·030*d.*	*x*
0·563*d.*	0·553*d.*	0·543*d.*	0·537*d.*	0·530*d.*	*y*
17,600	15,600	15,000	14,100	13,120	*z*
£41,680	£34,620	£29,250	£24,750	£21,000	A
£11,304	£9,354	£7,616	£6,522	£5,364	B
0·166	0·166	0·166	0·188	0·25	C
1·151	1·535	2·305	2·735	3·060	D
0·756	1·010	1·510	2·018	3·025	D'
3·058	4·080	6·120	7·488	9·145	E
3,215	7,680	25,750	56,000	154,000	F
22,505	53,760	180,250	392,000	1,078,000	G
0·42	0·76	1·70	2·78	5·09	H
£47	£112	£376	£817	£2,245	I
£376	£672	£1,504	£2,451	£4,490	J
£4,350	£4,350	£4,350	£4,430	£4,650	K
£313,000	£313,000	£313,000	£319,000	£335,000	L
£15,650	£15,650	£15,650	£15,950	£16,750	M
£9,400	£9,400	£9,400	£9,560	£10,050	N
£25,426	£25,722	£26,554	£27,961	£31,290	O
£36,730	£35,076	£34,170	£34,483	£36,654	P
£354,680	£347,620	£341,080	£343,750	£356,000	Q

APPENDIX II.

THE CENTRAL LONDON RAILWAY.

Some particulars of the electrical equipment of this railway may be convenient to the proper understanding of the figures relating to sub-station operating-costs. The Author has access, of course, to the operating-results of all the different plants with which he is associated, so that he is in a position to state that these operating-costs are representative. The reason why they are presented at such length is that they have been carefully kept over a longer period than applies to any other installation of the kind. The power-installation was designed to work a combined lighting, lift and train load, aggregating at normal maximum 5,000 kilowatts. The sub-station arrangement was to be such that the voltage should be maintained at all points within the limits applying to good lighting practice, and that there should be a duplicate sub-station supply to each section of railway. Since the failure of supply in the case of underground working, even temporarily, is of very serious moment, there are six sub-stations, three underground at the bottom of the lift-shafts and three on the surface. The underground stations have been very largely used since the opening of the railway, and, owing to the difficulty of ventilating them, they have seen abnormally hard service.

The transmission is at 5,000 volts, and it is worthy of note that there has not been a cable-failure since the opening of the railway. All the sub-stations are equipped with 900-kilowatt rotary converters, of the earlier type without interpoles, which convert three-phase 330-volt current at 25 cycles to continuous current at 525 volts. The rating is such that 900 kilowatts is the continuous output for 40° C. increase, 1,350 kilowatts for 1 hour, and 1,800 kilowatts peak load. There are ten of these, six underground and four on the surface. In the underground sub-stations there are three 330-kilowatt air-cooled transformers to each rotary. In the surfaoe sub-stations there are three 330-kilowatt water-cooled oil transformers. Since the opening of the railway there has been no interruption of service due to the failure of the electrical supply. The diversity-factor between the different sub-stations is of the order of 1·4 and the average working-efficiency is 90 per cent. The nature of the repairs and renewals is shown in detail in the Tables. With the exception of the switchgear, which has been subjected to great improvements in the period since the railway was opened, the plant is practically as installed. As will be seen in the records, the majority of the larger class of repairs has been caused by accident rather than by deterioration. For instance, a bank of air-blast transformers were burned out owing to the ignition of certain cables by a match being dropped in the air-blast duct. There have been five rotary-converter armature-failures in the 14 years the railway has been in operation. One was caused in transit by a screw in the packing-case penetrating the windings, another by a rivet dropping into an armature while running. The other three have occurred in the same machine in an underground sub-station where proper ventilation is very difficult to provide for. Twelve air-blast transformers have been rewound, the damage to nine of these being caused by overheating from lack of ventilation. It should be explained that sub-station operation was not in contemplation when the railway was begun, so that the disposition of the plant is not a normal one, and, in general, is unfavourable to efficient ventilation. The Central London Railway plant has been described at such length elsewhere that the present description is limited to what is required to complete the arguments on which the present Paper is based.

The costs associated with sub-station operation on the Central London Railway are shown in Table VII (p. 96), which gives the figures for each half-year from January, 1903, to December, 1913. Table VIII shows the repairs to sub-stations, set out in detail for the years 1906 to 1912.

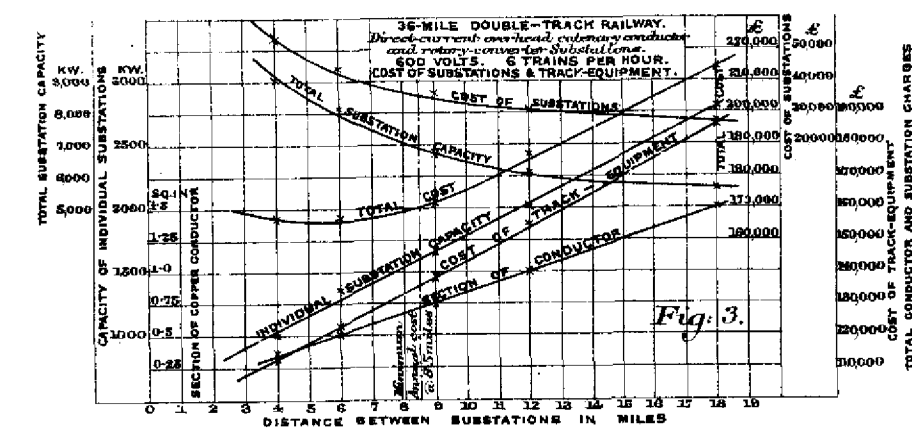
TABLE VII.—SHOWING INFLUENCE OF SUB-STATION CHARGES ON CENTRAL LONDON RAILWAY CURRENT-COST.

Half Year.	Units delivered from Power House to Cable System.	Total Cost per Unit delivered to Cables including Capital Charges.	Units delivered to Sub-stations (at 98 per Cent. Efficiency)	Transmission Charge per Unit delivered to Sub-stations.	Total Cost per Unit delivered to Sub-stations.	Units delivered from Sub-stations to Track, Lifts, etc. (at 88 per Cent. Efficiency.)	Sub-station Charges. Operating and Superintendence.	Sub-station Charges. Repairs and Renewals.	Sub-station Charges. Total.	Sub-station Charges. Operating and Repair Charge per Unit delivered.	Sub-station Charges. Capital Cost of Sub-station Plant and Buildings.	Sub-station Charges. Capital Charge per Unit delivered at 5 per Cent. per ann.	Sub-station Charges. Charge due to 12 per Cent. Loss.	Total Sub-station Charges per Unit delivered to Track.	Cost per Unit delivered from Sub-stations.
Working commenced Aug. 1900.	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
		d.		d.	d.		£	£	£	d.	£	d.	d.	d.	d.
1903 1st half	8,208,000	0·766	8,044,000	0·035	0·801	7,079,000	1,046	289	1,335	0·045	55,215	0·047	0·110	0·202	1·003
2nd ,,	7,888,000	0·813	7,730,000	0·037	0·850	6,802,000	1,116	171	1,287	0·045	64,391	0·057	0·116	0·218	1·068
1904 1st ,,	8,670,000	0·696	8,496,000	0·033	0·729	7,476,000	1,119	295	1,414	0·045	68,609	0·055	0·100	0·200	0·929
2nd ,,	8,821,000	0·704	8,645,000	0·033	0·737	7,608,000	1,378	524	1,902	0·060	72,131	0·057	0·101	0·218	0·955
1905 1st ,,	9,039,000	0·612	8,858,000	0·030	0·642	7,795,000	1,320	603	1,923	0·059	73,168	0·056	0·088	0·203	0·845
2nd ,,	8,955,000	0·589	8,776,000	0·041	0·630	7,723,000	1,441	482	1,923	0·060	74,297	0·058	0·086	0·204	0·834
1906 1st ,,	9,898,000	0·582	9,700,000	0·038	0·620	8,536,000	1,409	433	1,842	0·052	77,161	0·054	0·085	0·191	0·811
2nd ,,	9,306,000	0·572	9,120,000	0·039	0·611	8,026,000	1,540	82	1,622	0·048	81,170	0·061	0·084	0·193	0·804
1907 1st ,,	9,151,000	0·565	8,968,000	0·039	0·604	7,892,000	1,514	339	1,853	0·056	81,170	0·062	0·083	0·201	0·805
2nd ,,	8,383,000	0·628	8,215,000	0·043	0·671	7,229,000	1,503	240	1,743	0·058	82,500	0·068	0·092	0·218	0·889
1908 1st ,,	9,547,000	0·597	9,356,000	0·039	0·636	8,233,000	1,457	60	1,517	0·044	82,500	0·060	0·087	0·191	0·827
2nd ,,	9,888,000	0·584	9,690,000	0·038	0·622	8,527,000	1,406	173	1,579	0·044	82,963	0·058	0·085	0·187	0·809
1909 1st ,,	9,901,000	0·526	9,703,000	0·036	0·562	8,538,000	1,334	118	1,452	0·041	82,963	0·058	0·077	0·176	0·738
2nd ,,	9,567,000	0·496	9,375,000	0·037	0·533	8,250,000	1,392	104	1,496	0·044	82,963	0·060	0·073	0·177	0·710
1910 1st ,,	9,518,000	0·487	9,328,000	0·037	0·524	8,209,000	1,290	111	1,401	0·041	82,963	0·061	0·072	0·174	0·698
2nd ,,	9,577,000	0·491	9,375,000	0·037	0·528	8,250,000	1,330	59	1,389	0·040	82,963	0·060	0·072	0·172	0·700
1911 1st ,,	9,448,000	0·478	9,259,000	0·036	0·514	8 148,000	1,295	73	1,368	0·040	82,963	0·061	0·070	0·171	0·685
2nd ,,	9,166,000	0·471	8,983,000	0·037	0·508	7,905,000	1,266	50	1,316	0·040	82,963	0·063	0·070	0·173	0·681
1912 1st ,,	8,138,000	0·549	7,975,000	0·042	0·591	7,018,000	1,188	61	1,249	0·043	82,963	0·071	0·081	0·195	0·786
2nd ,,	9,035,000	0·516	8,854,000	0·038	0·554	7,792,000	1,300	57	1,357	0·042	82,963	0·064	0·076	0·182	0·736
1913 1st ,,	9,164,000	0·498	8,980,000	0·038	0·536	7,902,000	1,185	125	1,310	0·040	82,963	0·063	0·074	0·177	0·713
2nd ,,	8,530,000	0·513	8,360,000	0·040	0·553	7,354,000	1,199	48	1,247	0·040	82,963	0·067	0·075	0·182	0·735

TABLE VIII.—CENTRAL LONDON RAILWAY: SUB-STATION REPAIRS, WAGES, AND MATERIALS.

Half Year.	Switchboards.	Transformers and Blowers.	Rotaries (10,000 Kilowatts).	Cables and Connections.	Ventilating Plant.	Compressors.	Tools and Sundries.	Special Jobs.	Total.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1906, 1st half .	84 14 4	239 11 0	56 0 11	3 6 1	5 18 5	None	43 10 2	None	433 0 11
1906, 2nd „ .	20 14 9	52 15 6 credit	18 15 0	3 18 9	11 15 11	12 4 9	9 12 2	57 5 9	81 11 7
1907, 1st „ .	50 12 7	6 4 7	15 7 11	27 14 9	4 10 6	None	22 4 10	212 10 1	339 5 3
1907, 2nd „ .	83 11 7	16 12 3	19 6 1	4 1 9	84 2 6	None	17 4 4	15 9 8	240 8 2
1908, 1st „ .	23 19 4	1 2 3	4 5 10	0 12 4	19 1 10	4 2 8	3 17 8	2 9 4	59 11 3
1908, 2nd „ .	38 14 4	3 6 7	91 18 6	8 19 11	13 0 2	0 11 0	16 3 11	None	172 14 5
1909, 1st „ .	25 17 4	24 7 6	8 8 4	0 13 11	3 3 3	None	50 15 10	5 1 7	118 7 9
1909, 2nd „ .	13 9 9	7 17 0	73 4 0	2 18 6	0 10 11	None	6 10 6	None	104 10 8
1910, 1st „ .	31 0 8	3 5 0	20 18 7	9 19 2	16 11 11	8 3 4	12 8 1	8 5 10	110 12 7
1910, 2nd „ .	20 10 6	4 2 2	5 6 3	0 8 10	5 2 11	0 4 10	22 16 7	None	58 12 1
1911, 1st „ .	28 18 9	6 6 4	3 13 3	1 13 2	19 18 4	2 10 1	6 10 0	2 15 6	72 5 5
1911, 2nd „ .	20 3 4	4 4 4	1 15 0	1 2 9	18 0 11	0 7 4	1 1 3	3 8 2	50 3 1
1912, 1st „ .	8 16 10	2 1 5	38 19 7	0 5 7	10 2 6	0 7 3	0 5 6	None	60 18 8
1912, 2nd „ .	13 7 3	None	18 13 11	0 5 7	15 16 10	4 10 1	1 6 2	2 10 9	56 10 7
Total . .	464 11 4	266 4 11	376 13 2	66 1 1	227 16 11	33 1 4	214 7 0	309 16 8	1,958 12 5
Average annual expenditure .	66 7 4	38 0 8	53 16 2	9 8 8	32 11 0	4 14 5	30 12 5	44 5 3	279 16 1
Average per sub-station (four sub-stations) .	16 11 10	9 10 2	13 9 1	2 7 2	8 2 9	1 3 7	7 13 1	11 1 4	69 19 0
Percentage of total sub-station repairs . . .	23·7	13·6	19·2	3·3	11·6	1·8	11	15·8	100

ECONOMICS OF ELECTRIC RAILWAY DISTRIBUTION.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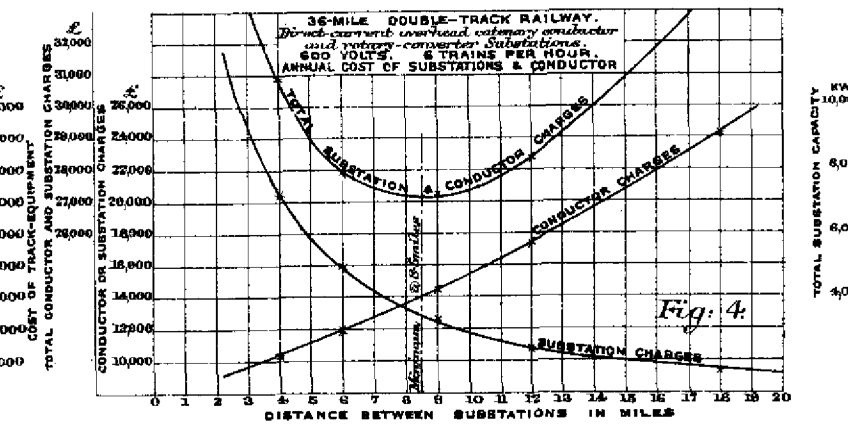
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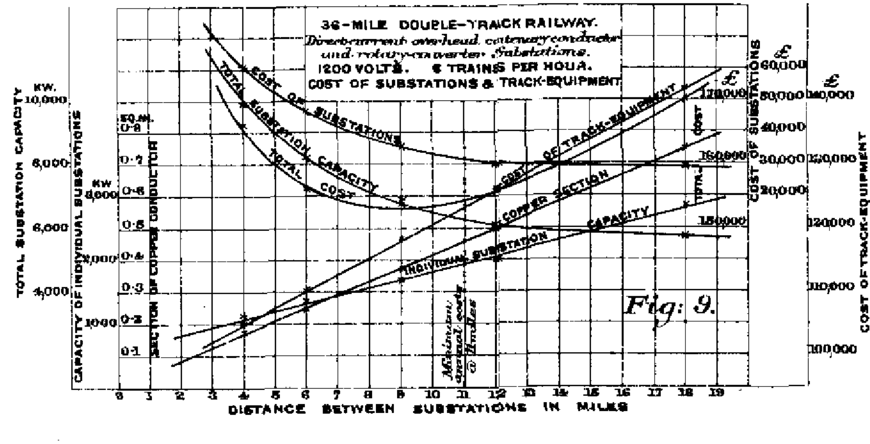
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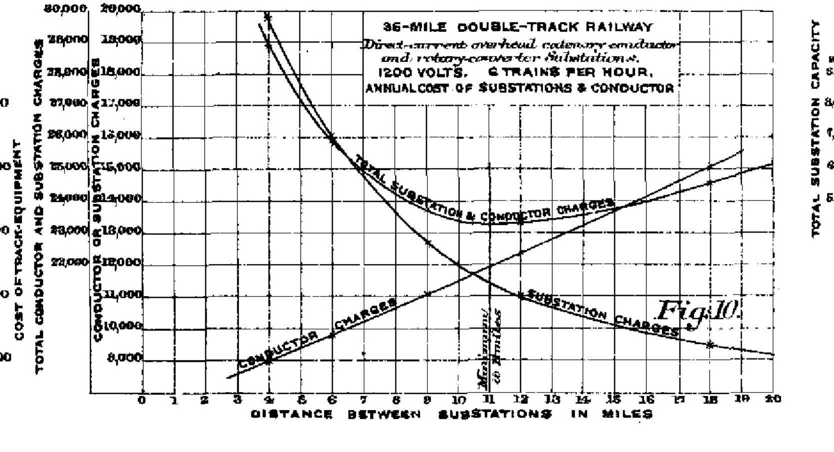
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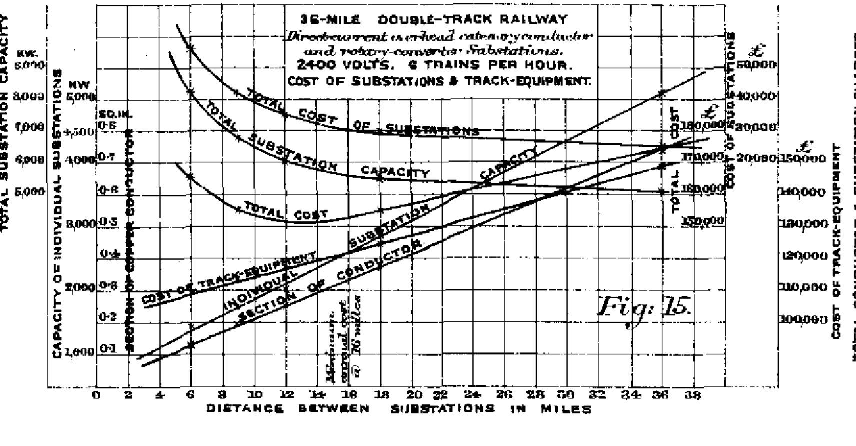
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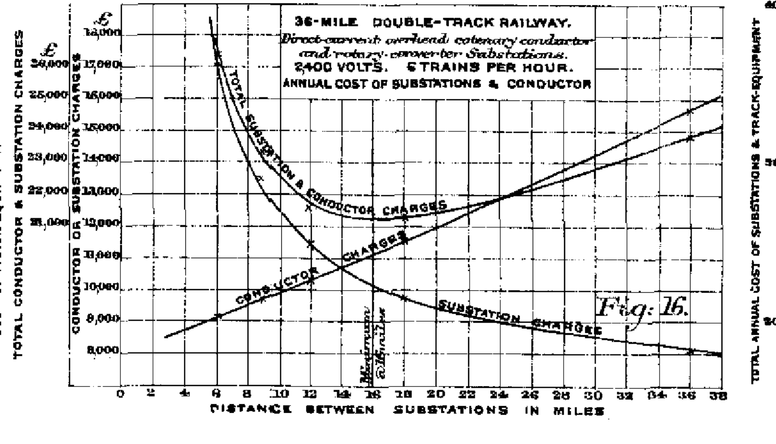
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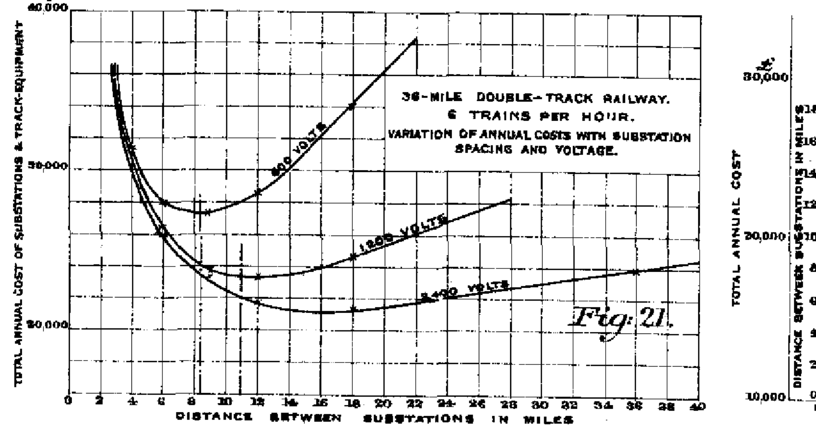
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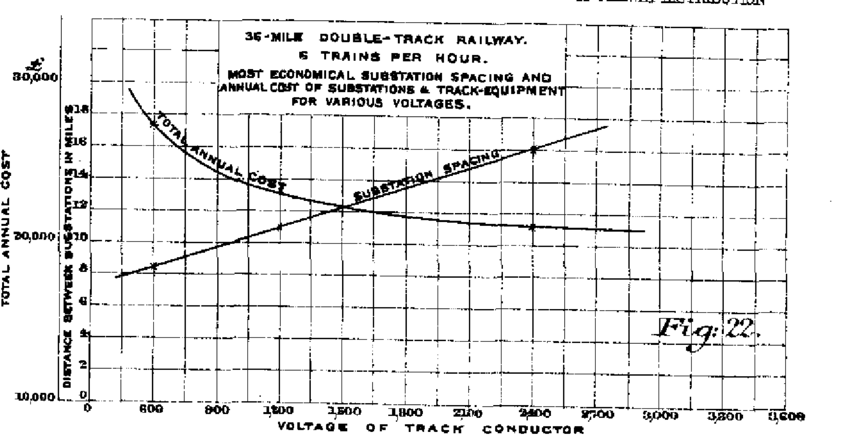
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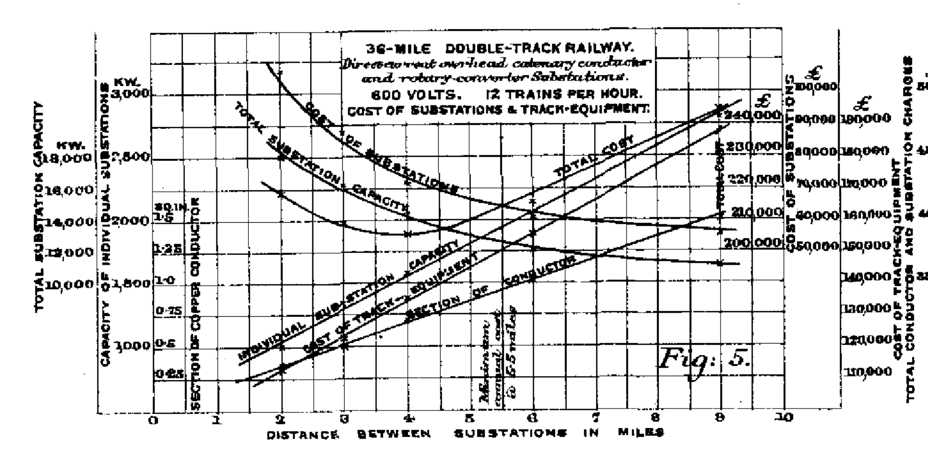
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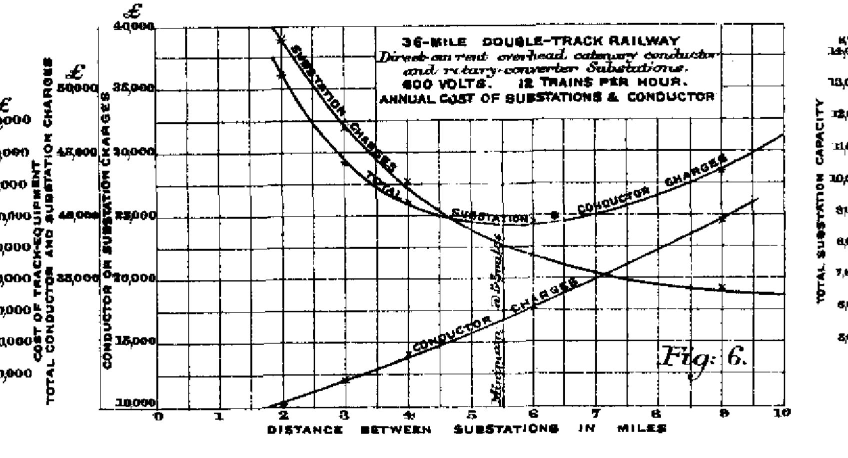
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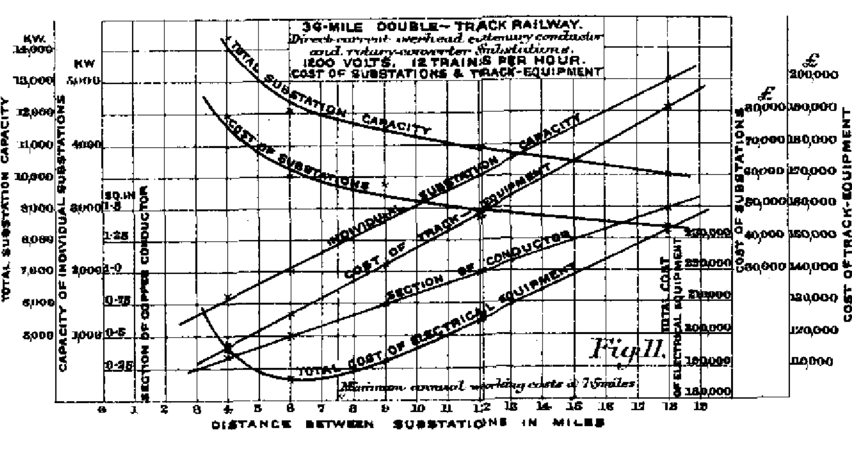
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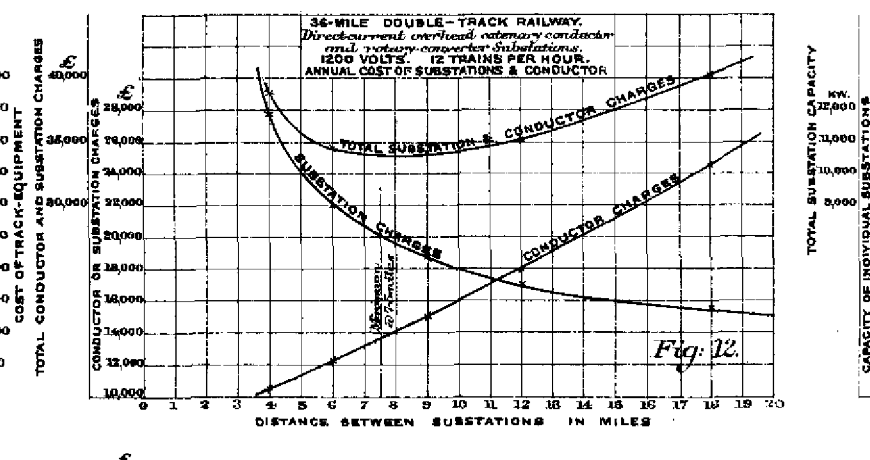
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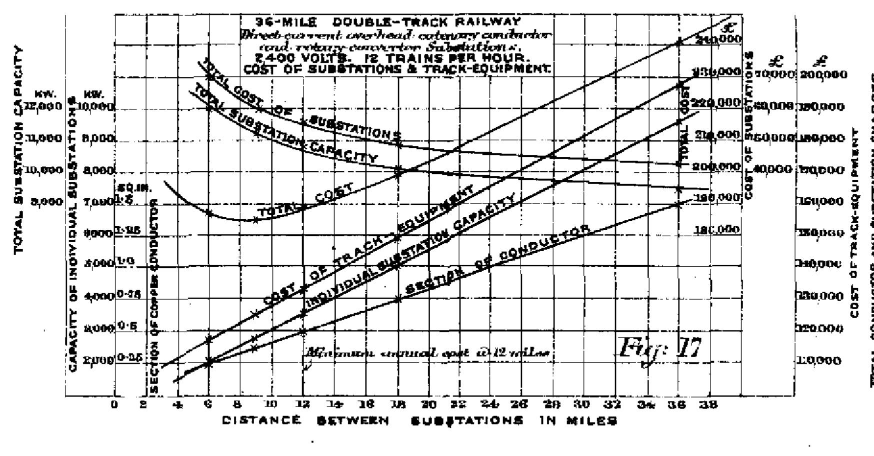
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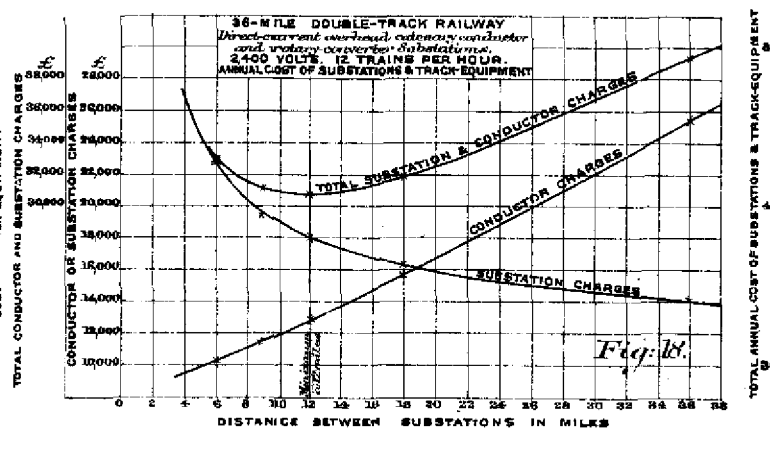
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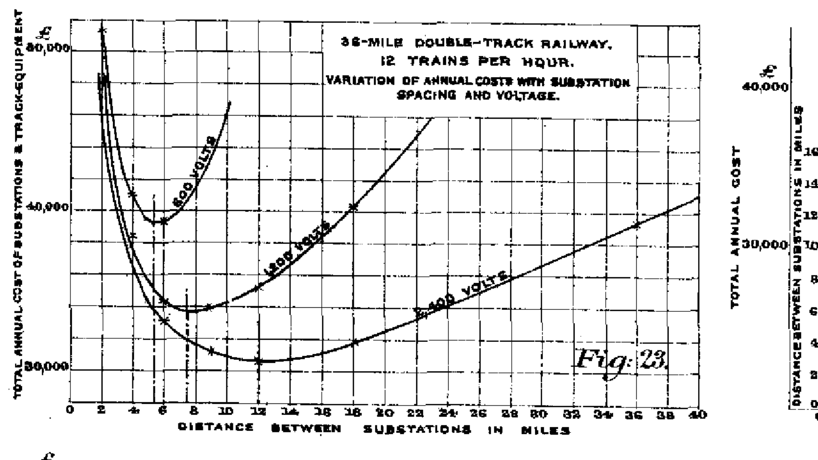
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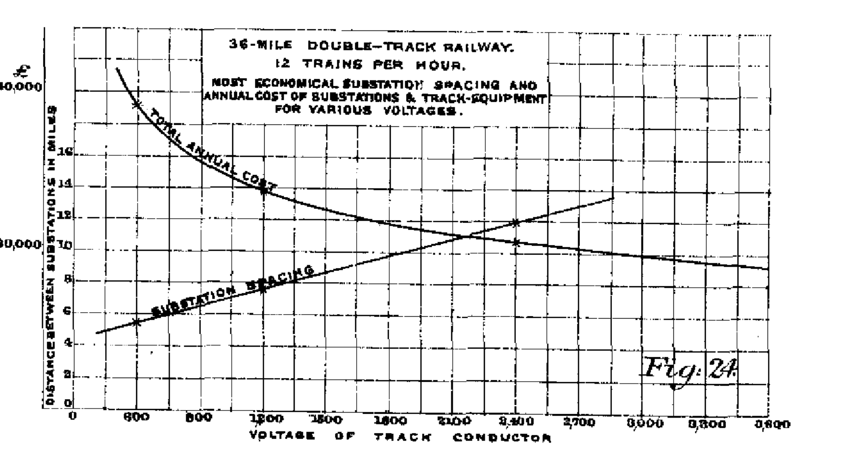
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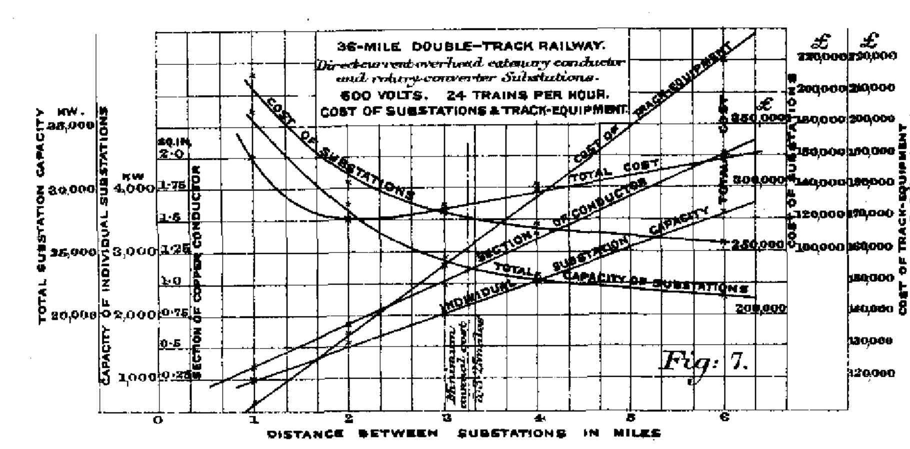
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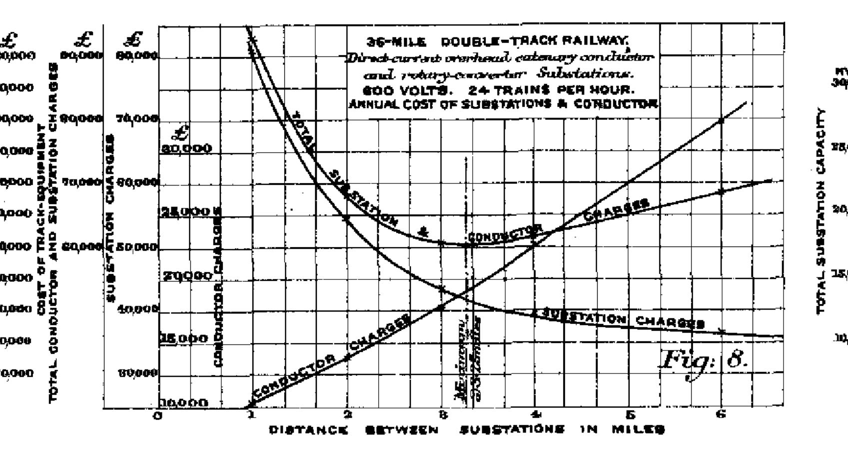
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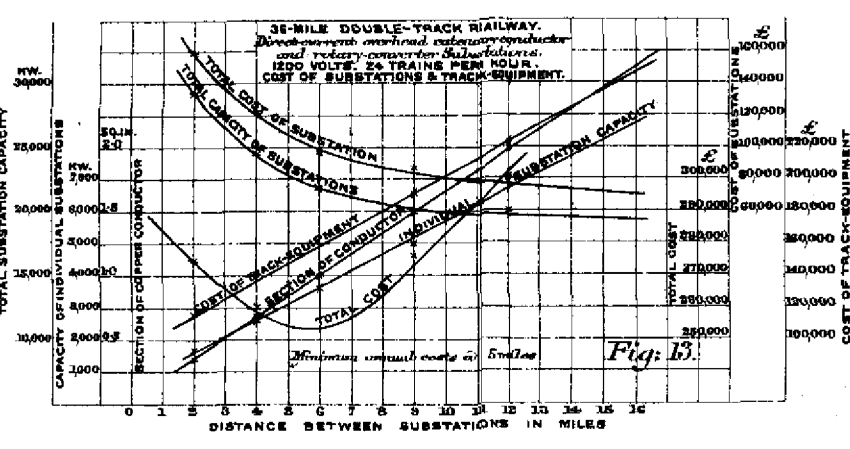
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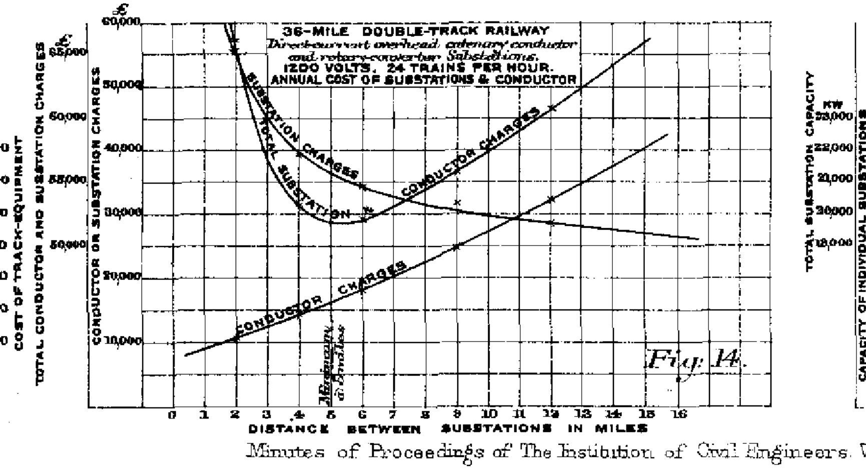
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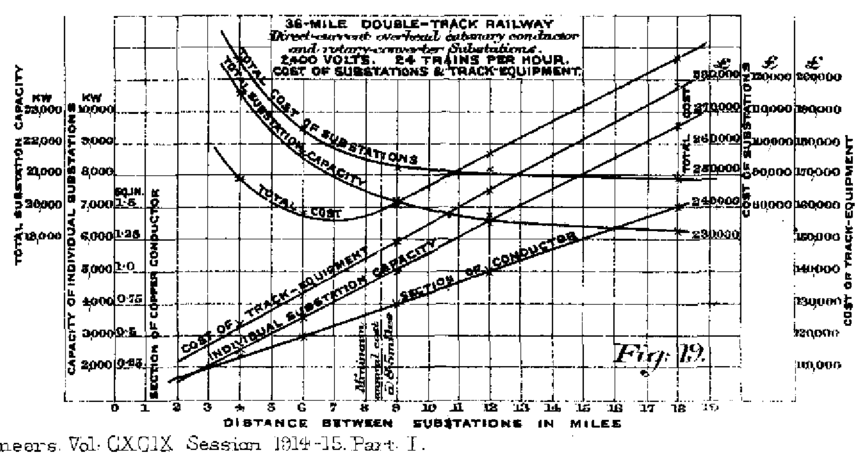
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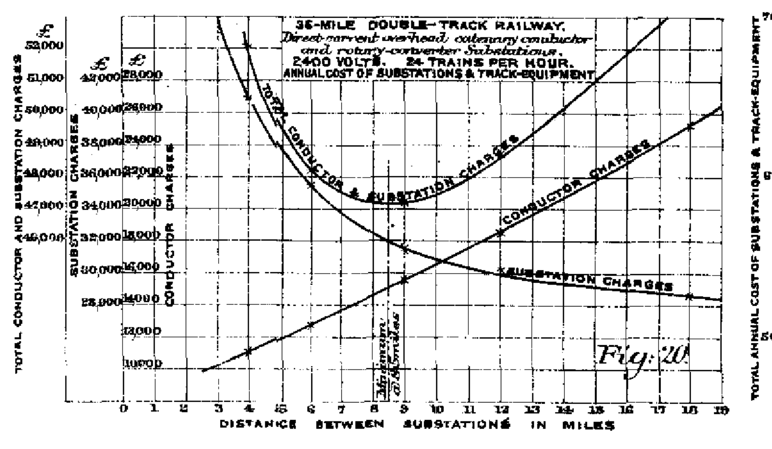
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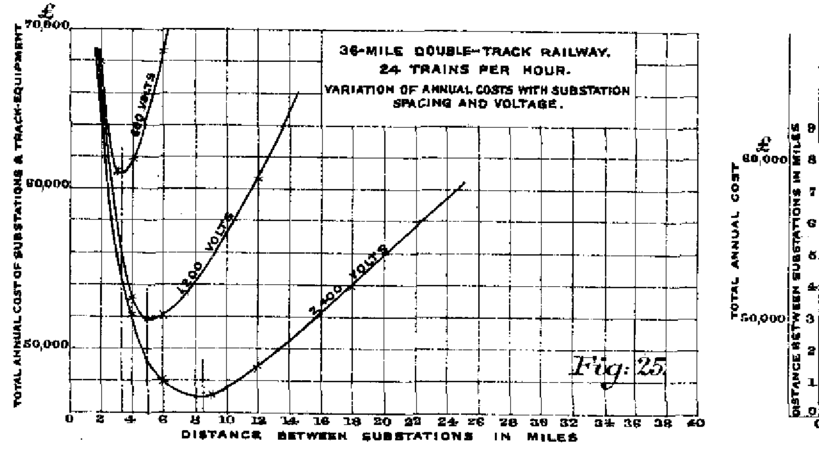
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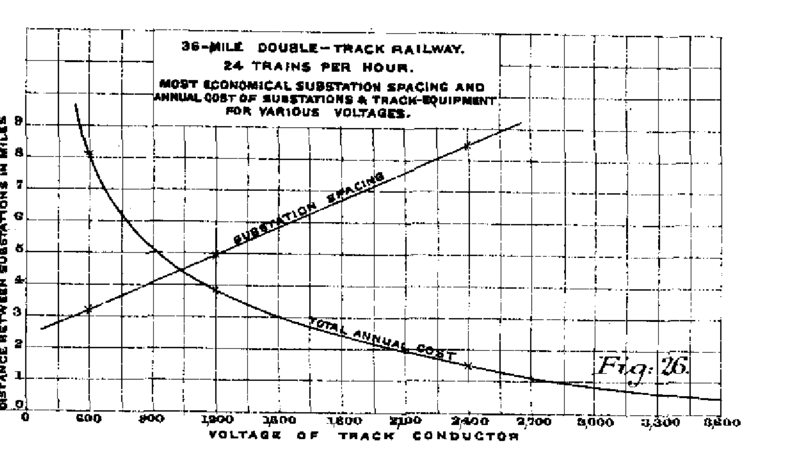
Fig. 26.

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ECONOMICS OF ELECTRIC RAILWAY DISTRIBUTION.

PLATE 3.