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INTERURBAN ELECTRIC TRACTION SYSTEMS, A.C. VERSUS D.C.

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Read before the Electrical Section, Nov. 19th, 1903.

Electric traction is peculiarly an American institution, that is, it has found its widest application in American communities and has been developed chiefly by American engineers. In America practically every town of over five thousand inhabitants is provided with an electric traction system. In other parts of the world it is only larger centres of population that are so provided.

Practically all the traction work in America has been done by direct current. The alternating current traction system, although it has received considerable attention from American engineers, has not until recently been favourably considered by them. In Europe, on the other hand, the alternating current traction problem has received a large amount of attention. The polyphase induction motor has been developed by European engineers for traction purposes and a number of installations have been made in Europe with apparatus of this character. American engineers have consistently refused to adopt the polyphase induction motor for traction purposes on the ground that it is not suitable for that purpose. The principal reasons for this stand are two in number.

(1). That the polyphase induction motor is inherently a constant speed motor and, therefore, not adapted to traction purposes. Continual change of speed is one of the characteristics of traction work. The direct current series motor is peculiarly adapted to this class of work because it is inherently a variable speed motor. At one definite speed the polyphase motor is an efficient machine, while at all other speeds the efficiency can not be greater than the ratio of the actual speed to the synchronous speed. For instance, if the actual speed at which a given induction motor is working is ten per cent. of its synchronous speed, the power utilized is at most only ten per cent. of the power put in. In traction work a large part of the work done is necessarily at speeds below the maximum attained, and at these lower speeds the maximum economy that can be obtained from induction motors is necessarily small.

One expedient used by European engineers to reduce this source of loss is the use of motors in concatenation or in tandem, that is, the secondary of one motor is fed into the primary of another on the same car. If the pair of motors thus concatenated are wound for the same number of poles, this expedient has the effect of making the synchronous speed of each of the pair of concatenated motors one-half that which it is when not in concatenation. It is equivalent in direct current practice to throwing two shunt motors in series. Up to the half speed joint, therefore, there is a gain of economy by this arrangement. By winding the two concatenated motors for different numbers of poles, more than one point of maximum economy can be secured between zero speed and full speed, but this arrangement has the disadvantage of being able to use but one-half the total motor capacity above half speed while the greatest expenditure of energy takes place above half speed. In order to secure the advantages of concatenation, however, it is necessary to add largely to the weight of the electrical apparatus. European practice has been to equip cars with four motors, two main motors and the other two being used only while the car is below half speed. Above half speed the motors are running idle and are doing no useful work. The energy required to take care of the additional weight is an offset against the energy which is saved by concatenating the motors. For long runs this expedient would probably be detrimental since the energy taken up to transport the extra weight would be more than equivalent to the energy saved at the start.

(2). The second reason against the use of polyphase induction motors for traction purposes is the necessity for providing at least two overhead conductors. If the track be not used as one of the conductors, then the necessity arises of using at least three overhead conductors. Maintenance of insulation on such overhead conductors when they are at high voltage is naturally a difficult problem, much more difficult than to maintain the insulation between a single conductor and ground, as would be the case in the single phase system.

American engineers instead of endeavoring to adapt the unsuitable induction motor to traction purposes, have devoted their energies to the development of a suitable alternating current motor. The idea of using a series motor operated by alternating current is not new. The only alternating current single phase motors which have a characteristic suitable for electric traction purposes are those of the commutator type. In no other type of motor are the speed and torque characteristics such as to be suitable for traction purposes. In the commutator type alternating current motor, the speed and torque characteristics are practically identical with these characteristics in the direct current series motor. As early as 1893 extensive experiments were made by the Westinghouse Electric & Manufacturing Co. on this class of motors. In fact, the experiments went so far as to equip a car with two motors of this type and the car was put into actual operation. Moreover, the frequency and voltage for which the motors were designed was practically the same as those for which the more recent motors were designed. These early motors were considerably smaller in capacity, however, and the trolley voltage was less. Further, the method of controlling the speed was by control of voltage. Although the early motors were successful as motors, the alternating current system as a system was not thought at that time of sufficient importance to continue the developments along this line. In other words, the time was not yet ripe for the development of this system. Interurban electric traction work, such as exists to-day, was not at that time thought of, and this is, in the writer's opinion, the peculiar field for the alternating current traction system.

In considering the general problem of electric traction, the question naturally arises,—what is gained by the use of alternating current over direct current ? and the converse of this question also naturally arises,—what is it necessary to sacrifice in order to obtain the benefit of alternating current traction ? An analysis of the advantages and disadvantages of these two systems may be of interest. Although many of the following points have been treated in previous papers, particularly that of Mr. Lamme, acting chief engineer of the Westinghouse Electric & Mfg. Co., before the American Institute of Electrical Engineers in September, 1902, it is hoped that repetition of some of the points mentioned will not be out of order.

The principal advantages of the alternating current electric traction over the direct current are as follows :—

(1). Limits to trolley voltage are removed.

(2). Avoidance of rheostatic losses.

(3.) The necessity for rotary converter sub-stations abolished.
(4.) Manual attendance at the sub-stations done away with.
(5.) Danger of electrolysis by return current avoided.

To take up these points more in detail :—

(1). VOLTAGE LIMIT REMOVED.—The greatest item of cost in the electrical equipment of interurban traction systems as they exist to-day is that of secondary distribution. This item of cost usually carries somewhere between twenty-five and fifty per cent. of the total for electrical equipment and is usually much nearer the latter figure than the former. Six hundred volts at the motor in a direct current traction system is practically the limit at which present designers and manufacturers are willing to guarantee their operation except in some special cases. This necessarily limits the voltage fed into the secondary distribution system to, say, seven hundred as a maximum. The consequence of this comparatively low voltage is naturally a high cost for conductors of this secondary distribution. The alternating current system, providing as it does the possibility of greatly increasing the voltage of the distributing system, thus cuts down largely the cost of this distributing system.

Another point which militates against the use of direct current is the fact that when large units are used it is difficult to collect the large amount of current for their operation. For this reason, as well as an advantage in cost, trolley construction has been largely replaced by the third rail for interurban work. By raising the voltage of the secondary system, the current taken by a locomotive may be reduced, and, consequently, the difficulty with collecting devices may be made to disappear.

(2). RHEOSTATIC LOSSES AVOIDED.—In the direct current system the voltage at the car is practically constant and while the counter E.M.F of the motors is building up, the excess voltage must be taken up by resistance. At the start, therefore, a comparatively large rheostatic loss occurs. With the alternating current system, on the other hand, the voltage at the car may be controlled by suitable means and the rheostatic loss thus avoided. When stops are few, and, consequently, runs are long, the rheostatic loss in the direct current system is a small proportion of the total, and, therefore, under these conditions this advantage of the alternating current system is not so greatly marked. With short runs, on the other hand, and, consequently, frequent starts, the rheostatic loss with the direct current system amounts to a considerably greater proportion of the total loss and the alternating current system, therefore, can have the greater advantage.

The curves in Fig. 3 show the superposed K.W. curves for a car equipped in one case with direct current motors and in the other with alternating current motors. The weight of the direct current car is thirty-five tons and of the alternating current car about eighteen per cent. greater. The length of run is two miles in each case and the schedule speed thirty miles per hour. Were it not for the saving of rheostatic loss, one would expect that the alternating current car equipment being eighteen per cent. heavier would take eighteen per cent. more power. The actual difference in the areas under the curves, however, shows about ten per cent. more power in the alternating current than the direct current on account of avoiding rheostatic loss in the alternating current equipment. If the run were for about one mile instead of two the consumption of power would be about equal, and for runs of less than one mile the alternating current power consumption would be less.

(3). NECESSITY FOR ROTARY CONVERTERS AVOIDED.—The cost of sub-station equipment constitutes one of the large items in the cost of the electrical equipment of an interurban road. In this substation equipment by far the largest item of cost is the rotary converters. In the alternating current equipment the rotary converter has no place, thus avoiding not only a large item of cost but also one of the largest items of the loss of power.

(4). ATTENDANCE AT SUB-STATIONS DONE AWAY WITH.—The direct current rotary being a piece of revolving machinery, of course, requires manual attendance at the various sub-stations. Alternating current sub-stations consist of static transformers only, and, therefore, require attendance only for the purpose of operating the switches. Making the switching devices entirely automatic in their operation avoids the necessity of attendance for this purpose. A still further requirement is the use of distant controlled switches operated from a central point, say the main power house. Electrically operated switches have already been developed to be operated from a distance of several hundred feet, and no reason exists why this distance of operation cannot be extended to twenty or thirty miles by proper design. By including in such a switch operating mechanism also a signalling device, by which the position of the switch is made known at the central point, the switch operating system becomes complete and no necessity exists for attendance at the alternating current sub-stations for any purpose except occasional inspection. There is, of course, an expense in connection with installing such a system of operating switches electrically, but it bears no comparison to the expense of manual attendance.

(5). ELECTROLYSIS.—Electrolysis of parallel conducting systems is generally recognized as one of the most serious dangers in connection with present direct current trolley systems, and the fact that an alternating current system avoids this danger entirely need only be mentioned in order to be recognized as a marked advantage.

So much for the advantages which accrue to the alternating current system. Now, the question arises,—what points must be sacrificed in order to obtain these advantages ? The disadvantages which necessarily accompany the use of the alternating current traction system are as follows :—

(1). Additional weight.
(2). Difficulty of operating on existing lines.
(3). Increased rail loss.
(4). The fact that an active E.M.F. exists between field turns.
(5). Possible interference with telephones.

Now, suppose the above points in detail be taken up.

(1). ADDITIONAL WEIGHT.—An alternating current motor of a given capacity is necessarily somewhat heavier and somewhat more expensive than a direct current motor for the same capacity. This difference in the motor, however, does not constitute the total difference in weights of equipment. In order to make use of the advantages of high trolley voltage, the alternating current equipment should preferably be provided with a step-down transformer on the car. Also, in order to obtain the advantages of avoiding the rheostatic losses, some provision must be made for controlling the voltage on the car. The transformer, the voltage control apparatus and the greater weight of motors makes the alternating current equipment necessarily heavier than the direct current. Although this difference need not, and,in many cases, will not be as great,—the example cited later in this paper (eighteen per cent.),—still a difference in weight will always exist detrimental to the alternating current equipment. This greater weight of the alternating current equipment is one of the items on the debit side of the ledger.

One of the most attractive methods for controlling the voltage on the motors is the use of an induction regulator. This is the form of regulator proposed by the Westinghouse Co. for use on the Washington, Baltimore & Annapolis Ry., the installation of which has been postponed on account of financial difficulties. The principal advantage over other forms is that it does not require the interruption of the current and is, therefore, of particular advantage in large equipments. It is this problem of breaking the current that forms not only the greatest difficulty with direct current equipments of large capacity but also one of the largest items in the deterioration account. The induction regulator has the advantage of adding considerably to the weight, and in equipments of comparatively small size where the difficulty of current interruption is not great, will probably be replaced by some other method of voltage control, such as loops or commutated coils on the step-down car transformers.

(2). DIFFICULTY OF OPERATING ON EXISTING LINES.—Practically all interurban roads run in and through cities on existing tracks, and, therefore, must use the existing sources of direct current power. In order to meet this condition, the equipment for an alternating current interurban road must be so arranged as to operate outside the city and on direct current inside. Although this is entirely possible, it must necessarily prove to be a matter of considerable complication. It means, in the first place, the use of motors which can be operated from both direct and alternating current. This is entirely possible with the series alternating current motor. It means, in the second place, that another system of control must be added to the car. This objection might in part be avoided by using rheostatic control for both the alternating current and direct current conditions, but the objection obtains that this method will deprive the alternating current system of its advantage of saving rheostatic losses. Further, means will have to be provided for disconnecting all transformers when running from direct current system and reconnecting them when running from alternating current system. All these matters, although they mean a considerable amount of complication, are entirely possible. The most important part of the equipment—the motors—can be operated from direct as well as alternating current.

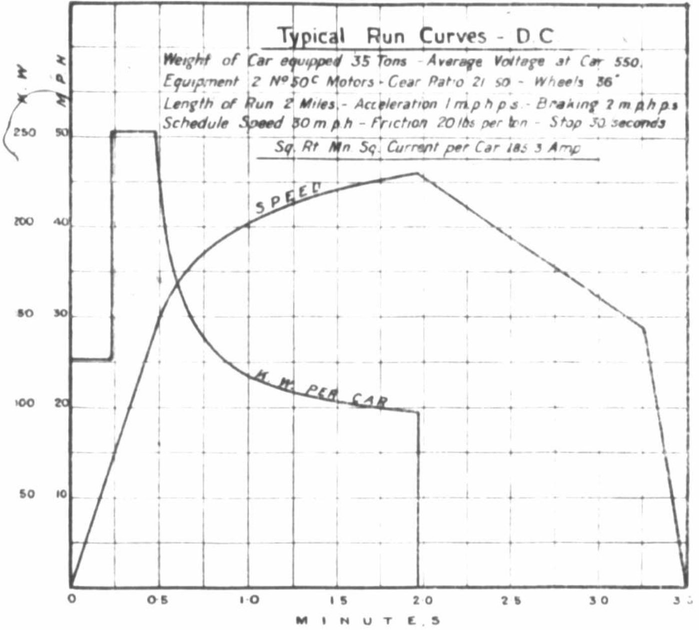
(3). INCREASED RAIL LOSS.—Experiments have shown that with alternating current from 2,000 to 3,000 alternations. the actual loss which takes place with a given current through the iron rails is from three to five times that which the same direct current would give. The ratios of loss hold for the higher frequencies. At first thought this seems to be an important objection to the A. C. system. But when it is considered that in order to utilize the main benefit of the alternating current, a higher trolley voltage is used, and, therefore, smaller currents in the return conductor. the element of rail loss in an alternating current proposition may be made even a smaller proportion of the total than in the direct current in spite of this apparently large handicap. The rail loss with direct current is usually a small proportion of the total and this with alternating current, at the trolley voltages which are usually considered, viz., 2,000 to 5,000, becomes a much smaller proportion.

(4). ACTIVE E.M.F. BETWEEN FIELD TURNS.—The space that can be assigned to the motor for operating a car is necessarily limited. It is this limitation of space, in fact, which often forces the use of a four-motor equipment instead of a two-motor equipment, the available space not being large enough to allow the installation of motors, two of which are sufficient for the work. When we consider the A.C. motor, the question of space available becomes still more exacting, first because the A.C. motor is necessarily heavier, and, therefore, occupies more space than an equivalent D.C. motor ; and second, because of the active E.M.F. that exists between the field turns in the A.C. motor, and which, other things being equal, again requires additional space for insulation. In the matter of E.M.F. between field turns, the A.C. and D.C. motors are quite different. The E.M.F. between the field turns of a D.C. motor is due simply to ohmic resistance and a short circuit between turns simply throws out of action the turns so short circuited, and if not too severe, does not interfere seriously with the motor's operation. Between field turns of the A.C. motor, on the other hand, there is an active E.M.F., similar to that between the turns of a transformer winding. A short circuit between field turns in an A.C. motor, therefore, means a destructive short circuit and an immediate interruption of service from that motor. In other words, the effect of a short circuit between field turns in an A.C. motor has the same effect that a short circuit between armature turns would have in either the A.C. or D.C. motors. Roasting out of field coils is one of the most frequent causes of trouble in D.C. motor equipments, and it is readily realized that this matter of active E.M.F. between field turns in the A.C. motor is a serious one. As an offset against this disadvantage of an active E.M.F. between field turns, the A.C. motor possesses the advantage of being capable of operation at low voltage, thereby reducing the number of turns on the series field and increasing the proportionate space for insulation. The use of a step-down transformer on the car makes available any desired voltage at the motor. This existence of an active E.M.F. between field turns is the most serious obstacle to the use of high voltage on the motor. Even with low voltage, the A.C. motor is labouring against the handicap of occupying more space than an equivalent D.C. motor, and the use of high voltage still further increases this handicap. The limitations of space do not apply to the transformer in anything like the same degree that they do to the motor and no particular difficulty is anticipated in building a transformer for this work.

This limitation of available space for the motor and the existence of an active E.M.F. between field turns makes it seem probable to the writer that the A.C. railway motor of the future will be operated at low voltage and will receive its current from a transformer situated on the car.

(5). INTERFERENCE WITH TELEPHONES.—It is a question whether alternating current in the rails will interfere with telephones and similar instruments more than the direct current which they have to contend with at present. In any event, the amount of current

Fig. 1

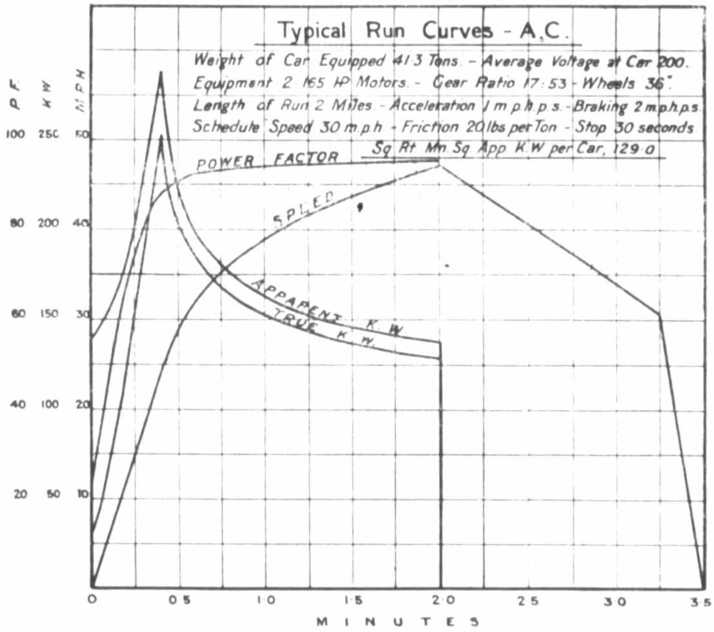


Typical Run Curves - D.C

Weight of Car equipped 35 Tons - Average Voltage at Car 550.
Equipment 2 Nº 50ᶜ Motors - Gear Ratio 21 50 - Wheels 36"
Length of Run 2 Miles. - Acceleration 1 m.p.h.p.s. - Braking 2 m.p.h.p.s
Schedule Speed 30 m.p.h - Friction 20 lbs per ton - Stop 30 seconds

Sq. Rt. Mn. Sq. Current per Car 185 3 Amp

Fig. 2


Typical Run Curves - A.C.
Weight of Car Equipped 41·3 Tons. - Average Voltage at Car 200.
Equipment 2 165 HP Motors. - Gear Ratio 17:53 - Wheels 36".
Length of Run 2 Miles. - Acceleration 1 m.p.h.p.s. - Braking 2 m.p.h.p.s.
Schedule Speed 30 m.p.h. - Friction 20 lbs per Ton - Stop 30 seconds
Sq. Rt. Mn. Sq. App. K.W. per Car, 129·0
POWER FACTOR
SPEED
APPARENT K.W.
TRUE K.W.
P.F.
K.W.
M.P.H.
100
250
50
80
200
40
60
150
30
40
100
20
20
50
10
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
MINUTES

in the rails can be reduced by the use of higher voltages so that this source of interference can be made less than it is with the present direct current system. Further, means have been proposed whereby the current can be confined entirely to separate conductors provided for the purpose, and not allowed to wander at will through any return circuit that may exist, as is the case with the direct current system. This can be done, of course, only at the expense of erecting a separate system for the return currents and a system of series transformers whereby these currents can be confined to this return system. The alternating current system, therefore, possesses the advantage of being able to use the rails for contact and still not allow the alternating currents to escape at will through the earth. As a matter of fact, interference with other circuits by the alternating current system is expected to be less than with the present direct current system.

The engineer has been defined as a man who could do for one dollar what any fool could do for two. The engineer, in other words, stands for efficiency. It is he who acomplishes a given result with a minimum expenditure of effort and money. Suppose we apply this criterion to the comparison between the A.C. and D.C. systems: By which of these systems can a given service be rendered most economically? In order to answer this question, we shall assume a certain typical interurban road, ascertain the first cost by both systems and the cost of operating by both systems and compare the results. Suppose the typical road which we will assume to be as follows:—

Length	60 miles.
Schedule speed..	30 M.P.H.
Cars running half hour apart.	
Number of stops..	30; that is typical run, two miles long.
Weight of D.C. car, complete..	35 tons
Weight of A.C. car, complete..	41.3 tons.

It may be noted here that the above difference in weight is not the minimum that can be obtained. A large part of the difference in weight comes, as previously stated, in the induction regulator, with which it is assumed the A.C. car is equipped. Other methods of voltage control can be supplied which would be considerably lighter, but the induction regulator is selected on account of the advantages previously mentioned. The A.C. system is, therefore, working under a handicap which is greater than would be the case if some other method of control were assumed.

Fig. 1 shows the speed-time and K.W. hours curve of a D.C. car of thirty-five tons over the typical run. The equipment, gear ratio, acceleration, etc. are given on the curve.

Fig. 3

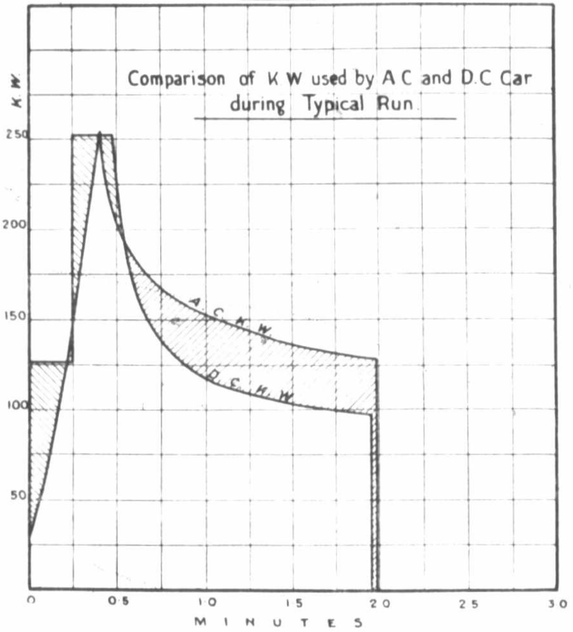

Comparison of K.W used by A.C and D.C Car during Typical Run.
K.W.
250
200
150
100
50
0
0·5
1·0
1·5
2·0
2·5
3·0
MINUTES
A.C. K.W.
D.C. K.W.

Fig. 2 shows the same for an A.C. typical run and in addition gives also the apparent K.W. and power factor. It will be noted that the difference in power at the car is only ten per cent. in favour of the D.C. equipment in spite of the fact that the differences in weight is eighteen per cent. in favour of the D.C.

The location of the power house is assumed in both cases to be on the line of the road midway between the termini, therefore thirty miles from each terminus.

In each case also one of the sub-stations is located in the power house. In the A.C. proposition the generators are wound for trolley voltage (3,000 volts) and fed directly into the trolley.

In each case also there are supposed to be four feeding points beside the power house, thus making the substitutions twelve miles apart in both cases.

Further, in both cases the secondary system is a single network, thus gaining the advantage of two feeding points except beyond the end sub-station. In neither system are secondary feeders figured on, the A.C. being simply a 4/0 trolley wire throughout and the D.C. a sixty-pound conductor rail. In the D.C. system the high tension line is supposed to be along the right of way of the road and the high tension poles are utilized for supporting the trolley wire with a bracket construction.

Recognition of the fact that the A.C. car is the heavier and requires more energy, is made, and larger motors than on the D.C. car estimated on.

In the D.C. proposition the generators, transmission line, etc. are supposed to be three-phase, naturally making necessary smaller transformers than in the single phase system.

The following parallel columns give complete comparison of the power consumption, the losses in the various transmissions and transformations, the first cost of the apparatus used and an estimate of the operating expenses. The conditions are taken as nearly as possible to those in the typical road. Location will, of course, make differences in many of the items considered, but especial care has been used in estimating those items in which the two systems present a difference.

D.C. RAILWAY SYSTEM.		A.C. RAILWAY SYSTEM.	
POWER REQUIREMENTS.			
Average K.W. at car in typical 2-mile run (Fig 1)	67.2 K W.	Average real K.W. at car in typical 2-mile run (Fig. 2)	73.9 K W.
No. cars running at one time	8	No. cars running at one time.	8
No. sub-stations	5	No. sub-stations	5

Average No. cars per sub-station	1.6	Average No. cars per sub-station	1.6
$\sqrt{\overline{\text{Mean amps. per car}}^{2}}$	185.3	$\sqrt{\overline{\text{Mean apparent K.W. per car}}^{2}}$	129.0
		$\sqrt{\overline{\text{Mean amps per car (3,000 volts)}}^{2}}$	43.0
$\sqrt{\overline{\text{Mean amps. per sub-station}}^{2}}$ = m	279 0	$\sqrt{\overline{\text{Mean amps per sub-station}}^{2}}$ = m	68.8
With sub-stations 12 miles apart, 80 lbs. track rail and 60 lbs. 3rd rail, resistance between adjacent sub-stations is = r	0.9 ohms.	With sub-stations 12 miles apart, 80lbs. track rail and No. 0000 trolley, resistance between sub-stations allowing for increased rail resistance	4.2 ohms.
D.C. line loss per sub-station $\frac{r\,m^2}{6}$ =	16.1 K.W.	Trolley and rail loss per sub-station = $\frac{r\,m^2}{6}$ =	3.32 K.W.
Average K.W. per sub station at cars = 67.2 x 1.6 =	107.5	Average real K.W. per sub station at cars = 73.9 x 1.6 =	118.0
Average K.W. per sub-station at sub-station	123.6 K.W.	Average real K.W. per sub-station at sub-station	121.32 K.W.
		% loss in regulator and car transformers	5 %
% loss in 3rd rail	15.5 %	% loss in trolley and rails	2.8 %
% loss in step-down transformers	3.5 %	% loss in step-down transformers	3.5 %
% loss in high tension line	2.5 %	% loss in high tension line	2.5 %
% loss in step-up transformers	3.5 %	% loss in step-up transformers	3.5 %
Total % loss from cars to P.H.	39.5 %	Total % loss	18.4 %
Average K.W. consumed by 8 cars at the cars	537 K.W.	Average real K.W. consumed by 8 cars at the cars	591 K.W.
Average K.W. at power house for 8 cars	750 K.W.	Average real K.W. at power house for 8 cars	700 K.W.
		Average apparent K.W. at power house, about	825 K.W.
Max. load per sub-station — worst condition — 2 cars starting	560 K.W.	Max. load per sub-station — worst condition — 2 cars starting (say 275 apparent K.W. each)	550 K.W.
One 400-K.W. rotor will take care of this 40 % overload.		One 350 K.W. transformer will take care of this with 50 % overload.	
Average load on rotary	30 %	Average load on sub-station, about	40 %
Rotary sub-stations are of sufficient size so that one can be cut out temporarily.		These transformers are sufficiently large to take care of road if one is cut out.	
Maximum load on P H., say	1,200 K.W.	Max. load on P.H. in apparent K W., say	1,400 K.W.

Can be taken care of with 3-400 K. W. generators, one for spare.	**Can be taken care of with 3-450 K. W. generators, one for spare.**

STEP-UP TRANSFORMERS.

7-150 K. W. transformers, one for spare.	3-400 K. W. transformers. Load can be carried by 2 in case of emergency.

HIGH TENSION LINE.

1-No. 6 B. & S. gauge line each way from P.H. 20,000 volt, 3-ph.		1-No. 3 B. & S. gauge line, each way from P.H. 20,000 volt, 1-ph.	
Max. loss, about	8.25 %	Max loss, about	8.2 %
Aver. loss, about	2.50 %	Aver. loss, about	2.5 %

SUB-STATION EQUIPMENT.

5-sub-stations in all—1 in P. H.	4-sub-stations—P.H. feeds directly into 3,000 volt trolley.
Each of 4 sub-stations to contain:	Each sub-station to contain:
3-135 K. W. step-down transformers.	1-350 K.W. transformer.
1-400 K. W. rotary converter.	Switchboard.
Switchboard	
Step-down transformers omitted in power house sub-station.	

LOW TENSION DISTRIBUTING SYTTEM.

Entire length of track equipped with 60 lb. conductor 3rd rail.	Entire length of track equipped with No. 0000 B. & S. gauge trolley.

CAR EQUIMENTS.

Each car with 2 150 H.P. D.C. railway motors and multiple control, apparatus complete.	Each car equipped with 2 165 H.P. A.C. railway motors with multiple control complete.

ESTIMATED FIRST COST OF ELECTRICAL EQUIPMENT.

POWER STATION.

3-400 K.W., 25 cycle, 360 V., 3 ph., A C. gens, at $6,500 each	$19,500	3-450 K.W., 17 cycle, 3,000 V., 1-ph., 2,000 alt. gens. at $7,000 each	$21,000
7-150 K.W., 350 to 20,000 V., self-cooling, oil-insulated trans. 25 cycle, at $1,225	8,575	3-400 K.W., 17 cycle, 3,000 to 20,000 V., O.I.S.C. trans. at $2,500	7,500
Switchboard	4,500	Switchboard	3,800
	$32,575		$32,300

HIGH TENLION LINE.

48 miles of 20,000 V., 3 ph transmission line, No. 6 B & S. gauge conductors at $900 per mile	$43,200	48 miles of 20,000 V., 1-ph. transmission line No. 3 B. & S. gauge conductors at $1,200 per mile	$37,600
Lightning protection	2,500	Lightning protection	2,000
	$45,700		$39,600

SUB-STATIONS.

2 135 K.W., 20,000 and 360 1 V., 25 cycle, O.I.S.C. transformers at $1,175 each . . .	$14,100
5 400 K.W., 600 V., 25 cycle rotary converters at $5,200 each.	26,000
5 switchboards at $2,800 each.	14,000
	$54,100

4-350 K.W., 2,000 alt., 2,000 to 3,000 V., O.I.S.C. transformers at $2,200 each. . .	$ 8,800
5 switchboards at $1,500 each.	7,500
Auxiliary signalling lines for operating the sub-station switches.	7,500
	$23,800

LOW TENSION DISTRIBUTION SYSTEM.

63 miles of 60 lb. conducting rail at $2,500 per mile installed.	$157,000
Bonding main track, 63 miles at $400 per mile.	25,200
	$182,200

63 miles of No. 0000 trolley wire in place at $900 per mile.	$56,700
Bonding main track, 63 miles at $400 per mile	25,200
15 miles of pole construction not included in H.T. lines, at $630 per mile	9,400
	$91,300

CAR EQUIPMENT.

12 D.C. car equipments, complete, consisting of 2 No. 50-C motors, with multiple control outfit, heaters and contact shoes at $5,217 each.	$ 62,604
Total first cost electrical equipment.	377,179

12 A.C. car equipments, complete, consisting of 2 157 175 H.P. motors, with multiple control outfit, heaters and trolley, at $8,482 each . . .	$101,774
Total first cost electrical equipment	$308,7[illegible]4

ESTIMATE OF YEARLY OPERATING EXPENSES.

D. C. System.

5 men at P. H., 2 shifts, aver. wage $900 per year each. . . .	$ 9,000
1 man at each of 4 sub-stations, 2 shifts, at $900 per year each.	7,200
Fuel, water, oil, etc., at ½ cent per K.W. hour, 4,890,000 K.W.-hr.	24,450
Repairs and maintenance of P.H (3 °/o of cost per year)	971

A. C. System.

5 men at P.H., 2 shifts, aver. wage $900 per year each. . . .	$9,000
Fuel, water, oil, etc., at ½ cent per K.W. hr..	$23,050
Repairs and maintenance of P.H. (3 °/o of cost)	969

Repairs and maintenance of H.T. line (5 % of cost per year)	2,285	Repairs and maintenance of H.T. lines (5 % per year)	2,980
Repairs and maintenance of sub-stations (4 % of cost per year)	2,064	Repairs, maintenance and inspection of sub-stations (6 %)	1,428
Repairs and maintenance of 3rd rail (1 % of cost per year)	1,822	Repairs and maintenance of trolley (4 % per year)	3,652
Repairs and maintenance of car equipments (12 % of cost per year)	7,512	Repairs and maintenance of car equipments 10 %)	10,177
Total yearly operating expenses	$55,404	Total yearly operating expenses	$51,256

NOTES ON THE ABOVE COMPARISON.

FIRST COST.—In the first cost of the two sytems above compared, no allowance is made for the fact that the A.C. system requires less energy at the power house, and, therefore, will economize to a considerable extent in both engines and boilers. On account of the greater apparent K.W. for the A.C. system, generators and transformers will be larger in capacity, but the engines and boilers need not be so great in capacity. So far as transformers are concerned, the A.C. system has the advantage because it allows the use of considerably larger units than the D.C. where three-phase transmission is necessary instead of single phase as is the case in A.C. system. The A.C. switch-boards also have the advantage in that two switches per panel are required instead of three.

To render a given service over high tension line, more copper is required for a single phase line than for a three-phase line, and this makes the copper for the A.C. system somewhat more expensive than for the D.C. system. The largest difference, however, in the high tension line items comes from the fact that the poles for the high tension line are spaced sufficiently close to allow the trolley brackets to be supported from the same poles. In the D.C. system, the spacing need be only sufficient for the requirements of the high tension line alone.

So far as sub-station transformers are concerned, the A.C. system has the advantage of single-phase over three-phase in that larger units are used. By far the largest item of saving in substation equipment between the two systems is, of course, in the omission of rotary converters in the A.C. system.

When we come to the consideration of the low tension distributing system we find at once the largest item of difference between the two systems. A glance at the comparative values will show that this difference in the case we have considered amounts to over $100,000, and is, therefore, nearly thirty per cent. of the total cost of the D.C. system.

In first cost the A.C. car equipments are, of course, considerably higher than D.C. The writer would call attention to the fact, however, that the costs of the A.C. car equipment include an induction regulator. If some other kind of regulator, such as, for instance, loops on the car transformers, had been figured upon, the cost of the A.C. car equipments might be diminished by something like six percent ; that is, something over $6,000. The saving in weight by the same change and the consequent saving of power in the A.C. system would amount to nearly four per cent. of that which has been figured upon. In the item of maintenance of the control apparatus, however, it is considered that the induction regulator has the advantage in that it is not necessary to break the current in going from step to step.

The A.C. system throughout is figured on the basis of using a frequency of approximately 2,000 alts. per minute. This frequency could be increased to, say, 3,000 alts. per minute at the expense of, first, a considerably decreased power factor, and, consequently, increased apparent K.W.; second, increased generator and transformer capacity ; third, increased line and rail loss ; and fourth, increased cost of motors. This difference might run the cost of the A.C. equipment, possibly as much as five per cent. higher than figured on. It will be noted, therefore, that the great saving comes in changing from direct current to alternating current, and that a change in frequency within moderate limits effects a change by no means comparable with that which is effected by going to alternating current.

OPERATING EXPENSES.—In the labour item it will be noted that the main saving comes in that sub-station attendance is avoided by the use of the A.C. system. In other respects, the labour items will be the same.

The fuel item for the A.C. system is somewhat smaller than for the D.C. system, as the actual energy at the power house is less in the former case than in the latter.

Besides labour and power, the main operating expense for any interurban railway system comes in the items of repairs and maintenance. It will be noted that this item of repairs and maintenance has been included in the above comparison by assuming that it is a certain percentage of the first cost in each case. There may be some difference of opinion as to the percentage that should be assumed in the various cases of this item of repairs and maintenance, but the writer has endeavoured to make the comparison between the two systems as fair as possible. It is not intended to include any item of depreciation in these repairs and maintenance figures. It will be noted that a marked difference is made between the maintenance of a third rail and trolley by allowing one per cent. in the one case and four per cent. in the other. The apparent discrepancy in allowing five per cent. for the maintenance and repairs on the high tension line and only four per cent. for that of the trolley is explained by the fact that the five per cent. on the high tension line includes the repairs and maintenance and the supporting structure for the trolleys.

The matter of inspection of the A.C. sub-stations is taken care of by allowing six per cent. in the case of the A.C. sub-stations instead of four per cent. as in the D.C. sub-stations.

In the matter of repairs and maintenance of the car equipments, it will be noted that twelve per cent. is allowed in the D.C. system and only ten per cent. in the A.C. system. Even this difference in percentage allows $10,000 per year for the maintenance of the A.C. equipments in the place of $7.500 for the D.C., or twenty-five per cent. more for the A.C. than for the D.C. The A.C. motors being lower in voltage and being protected from direct lightning discharges by the intervention of a transformer ought to have at least a no higher maintenance bill than the D.C. motors. The number of motors in each case is the same. The A.C. system, however, will require a certain amount of attention for the transformers and regulators. This item, though necessarily not based on experience, is estimated to represent the comparative conditions as closely as is possible at this time.