No. 1293*f*

THE ELECTRIFICATION OF RAILWAYS

AN IMPERATIVE NEED FOR THE SELECTION OF A SYSTEM FOR UNIVERSAL USE

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President of the Society

As an illustration of the wonders of the laws of nature, few inventions or discoveries with which we are familiar can excel the static transformer of the electrical energy of alternating currents of high voltage into the equivalent energy at a lower voltage.

To have discovered how to make an inert mass of metal capable of transforming alternating currents of 100,000 *volts into currents of any required lower voltage with a loss of only a trifle of the energy so transformed, would have been to achieve enduring fame. The facts divide this honor among a few, the beneficiaries will be tens of millions.*

209 In less than twenty-five years a new industrial and economic situation has been created by the development of apparatus to generate, distribute and utilize electricity. Not less than two thousand million dollars have been invested in plants to manufacture apparatus, in power houses to generate electricity, in lines of copper wire to transmit this mysterious energy, in construction of railways and their equipment, and in the manufacture of products unknown before the advent of electricity.

210 Large sums have already been spent in the electrification of portions of standard steam railways in England, continental Europe and America, and there is now available a fund of information of inestimable value to guide those charged with the selection of an electrical system for railway operations.

211 The president of our brother Institution of Mechanical Engineers, Mr. Aspinall, in his presidential address delivered April 23, 1909, placed the railway world under deep obligation for most valuable information upon the electrical equipment and operation of trains of the Lancashire & Yorkshire Railway, of which he is the

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worthy and skilful general manager. His observations on the effects of low center of gravity and heavy inflexible motor trucks upon the permanent way are especially valuable in that they direct attention to costs which at first were not considered with sufficient care.

212 Believing unreservedly that the increased capacity of a railway and its stations, the economies of operation, and other advantages will bring about gradually the systematic electrification of steam railways, my wish is that the progress of the art may not be hampered and such electrification of our main lines delayed or rendered unprofitable by mistakes which experience, judgment and foresight may enable us to avoid.

213 It is my intention in this paper to direct attention to the necessity for the very early selection of a comprehensive electrical system embracing fundamental standards of construction which must be accepted by all railway companies in order to insure a continuance of that interchange of traffic which, through force of circumstances has become practically universal, to the great advantage of transportation companies and of the public.

214 Having been identified with railway operations for over forty years, and with the development of the electrical industry for twenty-five years, I feel that the time is ripe for such a selection unless we are willing to regard with complacency the extension of the existing diversified systems and the creation of conditions which will prevent the general use of the most practical methods of operation.

215 Indeed, the tendency seems to be toward diversity rather than unity, since different types of third-rail construction have been adopted, even for the several continuous-current systems in and about New York City, which renders interchange of cars or locomotives difficult or impossible.

216 Although the facts clearly show the contrary, there exists a popular impression that the electrification of railways is a simple matter, and that it requires only decisions by boards of directors to insure the immediate substitution of the electric for the steam locomotive.

217 The great difficulty in the electrification of standard railways is no longer the engineering problem of developing a locomotive and an electrical system which will operate trains, but it is a broad question of financial and general policy of far-reaching scope, considering the future electrification of railways in general as distinguished from isolated cases of limited extent, and requiring a combination of the highest engineering and commercial skill.

GAGE OF TRACK AND INTERCHANGE OF TRAFFIC

218 In the first days of railway operation, there was probably no idea of an interchange of traffic involving the use of the engines and cars of one railway upon the lines of another railway. It then made no difference whether the gage of track was 4 ft. 8½ in., the one ultimately selected, or one of a greater or lesser width by a few inches. The gage selected by Stephenson was a practical one, fortunately, since it has become almost universal, with a strong probability that it will one day be absolutely so.

219 Stephenson's successful demonstrations prompted experimenters in other countries, who naturally failed to appreciate the inconvenience and losses which were to follow the adoption of different gages. The general tendency to extend along the line of least resistance, made it inevitable that a railway once started upon a certain gage would make no change, and thus there were developed systems of railways with different gages of track. In the early days too, there were those who believed it to their advantage to establish a gage of track that would absolutely prevent the cars and engines of a connecting line from coming upon their line.

220 In some cases in the United States the difference in gage was, fortunately as it afterwards proved, only 1½ in., a difference successfully met, for the purpose of interchange of traffic, by the adoption of broad-tread wheels and minor changes in the track construction. In other cases, the gages adopted were 5 ft., 5 ft. 6 in., and 6 ft., and in some of these cases the necessity for through passenger traffic led to the changing of car trucks, at certain important places, so that passengers could be transported through to their destination without changing cars.

221 In 1878 there were in the United States eleven different gages of railroad tracks in addition to the standard gage of 4 ft. 8½ in.

222 The absolute necessity for uniformity of gage of tracks both in the United States and Canada became so apparent that in due course all of the roads which had gages wider than 4 ft. 8½ in. changed to the present standard. Among the remarkable achievements of engineering was the change of the tracks of an entire system of railway of some hundreds of miles within twenty-four hours, this change having, however, required months of preparation. The losses entailed in the change of gage and of equipment have ever since been serious burdens to most of those railways, in that the costs were in most cases covered by capital charges.

223 It may be conceded that, so far as steam railway operation

is concerned, there are now no obstacles to the interchange of traffic in the broadest sense, except in the size of vehicles in certain countries where the cost of changing tunnels and bridges would be prohibitive.

REQUIREMENTS FOR INTERCHANGE OF TRAFFIC

224 With these preliminary remarks I feel certain you will agree that to insure interchange of traffic, the fundamental requirements, so far as operation by steam is concerned, with full regard for safety, speed and comfort, are very few in number and are covered by the following:

a A standard gage of track.
b A standard or interchangeable type of coupling for vehicles.
c A uniform interchangeable type of brake apparatus.
d Interchangeable heating apparatus.
e A uniform system of train signals.

The additional fundamental requirements for electrically operated railways are:

f A supply of electricity of uniform quality as to voltage and periodicity.
g Conductors to convey this electricity so uniformly located with reference to the rails that, without change of any kind, an electrically fitted locomotive or car of any company can collect its supply of current when upon the lines of other companies.
h Uniform apparatus for control of electric supply whereby two or more electrically fitted locomotives or cars from different lines can be operated together from one locomotive or car.

225 Outside of economy in capital expenditure, and economy and convenience in operation by steam or electricity, it matters not whether each locomotive and car and the apparatus upon them differ from every other locomotive and car in size or details of construction, so long as the constructions are operative and the materials employed are used within safe limits.

DEVELOPMENT OF ALTERNATING-CURRENT APPARATUS

226 Having acquired a considerable experience in the introduction upon railways of the compressed air-brakes and in the development of automatic electro-pneumatic signals, I was led in 1885, because of its general analogy to operations with which I was familiar, to interest myself in the American patents of Gaulard and Gibbs (a Frenchman and an Englishman), covering a system of electrical distribution by means of alternating currents, with static trans-

formers to reduce these currents from the high voltage necessary for economical transmission of electrical energy to the lower voltages required for the operation of incandescent lamps and other purposes.

227 No inventions ever met with greater opposition in their commercial development than those relating to the generation, distribution and utilization of alternating currents, and it is a matter of record that the opponents of those interested in developing the alternating system even sought, through public meetings and the appointment of commissions, and by various extraordinary means, to influence and prejudice public opinion.

228 Realizing the limitations of the continuous or direct-current system, I became thoroughly convinced that the extended distribution of electricity for industrial purposes could be secured only by the generation of alternating currents of high voltage and their conversion by static transformers into currents of various voltages. Notwithstanding, therefore, the frank disbelief in its practical value by eminent scientific authorities, among them the late Lord Kelvin, I entered actively into the development of the alternating-current system of generation and distribution of electricity which is now almost universally accepted as the ideal.

229 By 1888 Nikola Tesla had demonstrated the practicability of his induction motors, Oliver B. Shallenberger had perfected his meter for measuring alternating currents, and it had been proved that a direct-current motor with laminated armature and fields could be operated either by alternating or by direct currents. I then became thoroughly imbued with the belief that further invention and discovery would in time make alternating-current apparatus practically universal for almost every purpose.

230 In 1892 two single-phase motors of about 10 h.p. were built by the Westinghouse company to determine the possibilities of using alternating current for traction work. These motors were designed for 2000 alternations per minute and about 200 volts. They were of the series type, with commutators, and had a relatively large number of poles. These were placed upon a car and tested on a short piece of track with very short curves and rather steep grades. There was a transformer on the car on which there were several taps and the voltage was varied by means of single-pole switches. It was considered at that time that the system would be ideal for locomotive work, but as there were no such projects in view, no large motors of this type were built. This development is referred to more at length in Appendix No. 5.

231 All so-called continuous- or direct-current generators really generate alternating currents and transform them by a commutator into continuous current, and such a machine will, by the application of collector rings upon its armature, deliver both alternating and continuous currents. The use of the commutator, however, so limits the voltage that large quantities of power cannot be generated for economical transmission by direct current. A machine so constructed can also receive alternating currents through the collector rings and transform them into direct current. As thus used the apparatus is called a rotary converter. When the supply of alternating current is at very high voltage, there has to be interposed between this supply and the rotary converter a static transformer to reduce the high primary voltage to the permissible lower voltage.

ELECTRICAL SYSTEMS FOR RAILWAYS

232 As soon as these qualities of the alternating current had been demonstrated, active minds were directed toward the development of apparatus to meet conditions constantly presenting themselves, among the most important problems being the electrification of railways. In the twenty years that have elapsed, three important electrical systems for the operation of railways have been put into practical operation, all using alternating current in whole, or in part. These systems are:

a The continuous- or direct-current system, usually spoken of as the "third-rail" system, which employs alternating current for transmitting power when the distance is considerable.

b The three-phase alternating-current system with two overhead trolley wires.

c The single-phase, alternating-current, high-tension system with a single overhead trolley wire.

233 In a notable case of the latter system, namely, that of the New York, New Haven & Hartford Railroad, the motors and controlling apparatus are arranged to utilize single-phase current from an overhead trolley wire at 11,000 volts, and also to be operated by current from the 650-volt third-rail system of the New York Central & Hudson River Railroad, thus making a demonstration of the wonderful flexibility of alternating-current apparatus.

234 The problem before the officials of the New Haven road was not merely the electrification of a division of a few miles of its track, rendered compulsory by legal requirements, but the selection of a sys-

FIG. 18 SINGLE-PHASE ELECTRIFICATION OF THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

VIEW SHOWS TROLLEY WIRE SUPPORTED BY DOUBLE STEEL CATENARY CABLES SUSPENDED FROM LATTICE STEEL BRIDGES OVER THE FOUR TRACKS. THE ONLY ELECTRICAL CONSTRUCTION ON THE TRACK LEVEL IS THE SMALL COPPER BONDS CONNECTING THE RAILS.

tem which would meet the needs of a great railway covering several states and having other congested centers of traffic which it might soon be desirable to electrify. In view of the fact that there had been no considerable demonstration of the single-phase system by actual use, and that the New Haven trains would be obliged to operate upon twelve miles of lines already equipped with the direct-current third-rail system, it must be conceded that the directors and management of the New York, New Haven & Hartford Railroad showed great courage and confidence in the judgment of their experts. and rendered to all other railroads a service of the highest character, when they selected the single-phase system for the electrification of the line mentioned.

235 As the single-phase method of operation is comparatively recent and is not so well known as the other systems, extended particulars are given in the appendices upon the extent of operation by this system, and upon the results attained in its use by the New York, New Haven & Hartford Railroad. The important experiences gained on that railroad furnish very important data to aid in the selection of a uniform system of electrical railway operation.

236 The paper[1] by Mr. George Gibbs, chief engineer of electric traction of the Pennsylvania Railroad, with reference to the electrifications by that company, submitted in June of this year to the International Railway Congress at Berne, Switzerland, gives most valuable particulars in regard to the practical electrical operation of a standard railway.

237 When the officials of the New York Central Railroad and those of the New York, New Haven & Hartford Railroad, who now have had an unusual experience, also present their available facts as to cost of installation, of maintenance and of operation, the railway world will have very complete information.

238 The results of the working of the three-phase system in Italy and Switzerland have been very prominently before the world for several years, and its successful use there has been a material factor in the development of confidence in electricity for the operation of railway trains. At the present time, the Italian Government is installing upon the Giovi line, which is a heavy-grade branch leading out of Genoa, a service for which twenty locomotives, rated at 2000 h.p., are now being constructed in Italy. The operation of this

[1] The report is entitled Electric Traction: Electric Traction on Large Railroads; Continuous Current; Alternating Current (Monophase or Polyphase); Comparative Net Cost. It appears in the Bulletin of the International Railway Congress Association, under Question 8, Report No. 2, by George Gibbs.

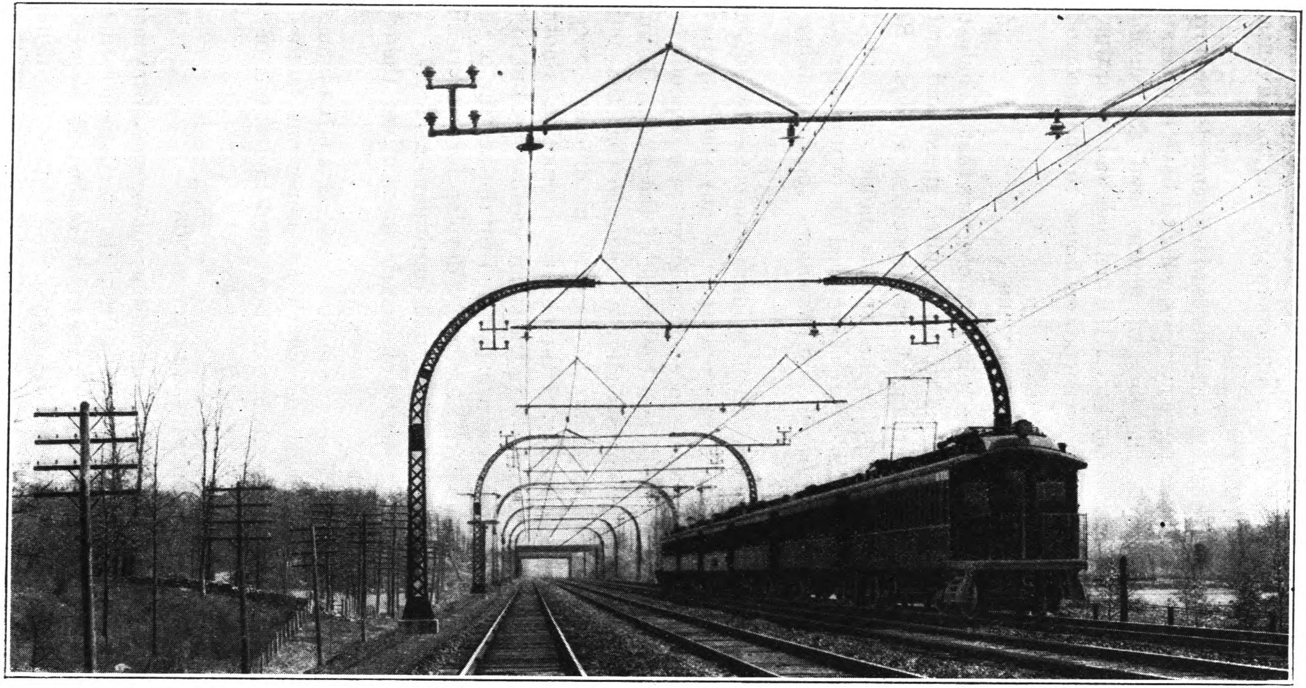


Fig. 19 Multiple Unit Train for Suburban Service; Overhead Construction of New Type Developed by the New York, New Haven and Hartford Railroad

much more extensive plant will afford additional valuable information as to the cost of installation and operation, and the advantages of the three-phase system.

239 The equipment of the power houses which generate the current is essentially similar in the three systems which I have enumerated; but the systems differ in the kind of motors and the auxiliary apparatus for controlling them, and in the methods and apparatus for transmitting the current from the power house to the locomotive or car.

RAILWAY MOTORS

240 Essential requisites in a railway motor are that it shall start its load and quickly accelerate it to the required speed, and that it shall operate continuously at any desired speed, or speeds. Railway conditions make it desirable that speeds should vary from the lowest to the highest schedule speeds required for regular operation, both for the movement of freight and passengers, and for making up time.

241 The steam locomotive, which is limited in power by its boiler capacity, is capable of continuous operation at any speed up to the maximum, but the maximum speed in a given case depends both upon the length of the train and the grade of the track. It automatically slows down when ascending a grade, so that the actual horsepower developed does not vary greatly at different speeds. The limitation of the capacity of the electric locomotive is not the power available, as is the case with the steam locomotive, but in the capacity of the motors, and is usually fixed by the heating of their coils. An electric locomotive may safely develop for a short time an output which far exceeds its normal continuous capacity. The power and speed characteristics of electric locomotives therefore differ from those of steam locomotives.

242 The three types of electric motors have certain fundamental differences in speed performance which are important factors in determining the advantages, disadvantages and limitations of the several systems.

THE DIRECT-CURRENT MOTOR

243 The characteristics of the direct-current series railway motor are well known. It automatically adjusts its speed in accordance with the load, running more slowly if the weight of the train be greater, or the grade steeper. The speed with a given load, however, is definite; it is dependent upon the voltage applied to the motor and cannot

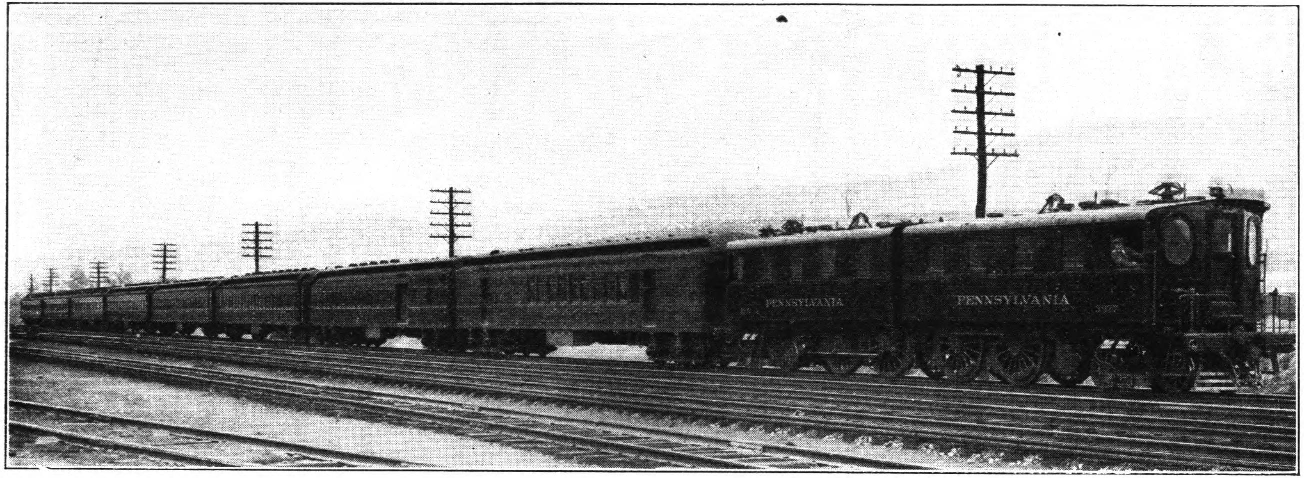


FIG. 20 PENNSYLVANIA ELECTRIC LOCOMOTIVE WITH ALL STEEL CAR TRAIN FOR OPERATION INTO THE NEW YORK STATION

readily be varied. It is true that the speed can be decreased by inserting a resistance in the motor circuit, but this is wasteful and is inadmissible except as a temporary expedient. It is true also that the motors may be connected in series, thus dividing the pressure between two motors, and thereby reducing the speed one-half; or if among four motors, to one-quarter speed. As the system of current supply involves a fixed voltage, it is obvious that for emergencies no speeds much above the maximum speed determined in the construction of the motor can be obtained. Furthermore, on account of the high cost involved in maintaining a practically constant voltage throughout the system, the voltage supplied to the motors often decreases considerably at the end of long lines, at the time of heavy load, thereby further reducing the speed attainable. It often happens in railway service that a locomotive should be operated somewhat above the normal speed, and sometimes a locomotive designed for freight service has to be pressed into passenger service. In such cases the speed with the direct-current locomotive would be considerably less than that necessary to maintain the schedule speed. A special form of field control can be used, in certain cases, for varying the speed, although this has so far been utilized to a very limited extent.

THE THREE-PHASE MOTOR

244 On the three-phase system, the motor is inherently a constant-speed motor; it runs at approximately the same speed at light load and at full load; it runs at nearly the same speed up a grade as on level track, although the horsepower required on the grade may be several times that on the level. Conversely, it can run no faster on a level than it can climb a grade. In order to give a lower speed, however, the motors may be arranged upon the locomotive in pairs in a manner equivalent to the arrangement of two continuous-current motors in series, just described. Motors may also be arranged for two or more speeds, but this involves some complication in windings and connections. In all cases lower speeds can be secured by the introduction of resistances which increase the losses and lower the efficiency. In no case can the speed in any of the arrangements of motors be appreciably higher at very light load than it is at full load.

245 The motors are of the induction type without commutators and their inherent limitations, and are of relative simplicity in construction. The current is usually supplied at 3000 volts from two overhead lines through two sets of current collectors.

246 With three-phase motors as now constructed and arranged upon locomotives, it is possible with no additional complication so to utilize the motors when locomotives are moving trains upon a descending grade, that they become generators and return current to the line, a feature of value in certain mountainous districts but not of controlling importance in the selection of a universal system.

THE SINGLE-PHASE MOTOR

247 The single-phase railway motor is a series motor with speed characteristics very similar to those of the direct-current motor,

FIG. 21 TYPICAL SECTION SHOWING THIRD RAIL, TRANSMISSION LINE AND SIGNAL BRIDGE OF THE NEW YORK CENTRAL AND HUDSON RIVER RAILROAD

as the speed at a given voltage is greater or less, depending upon the load. The speed with a given load is also greater or less, depending upon the pressure applied to the motor; and this is not limited, as with direct-current motors, to that supplied by the circuit, and to one-half and one-fourth of that pressure, but is capable of adjustment to any desired degree of refinement by means of auxiliary connections from the secondary winding of the transformer on the locomotive, which is necessary for reducing the line voltage of 11,000 volts to the lower voltage required by the motors. Not only may numerous voltages less than the normal be arranged for lower speeds, but higher voltages can be provided to make possible speeds considerably above the normal. In this simple manner a wide range of efficient speed adjustment is secured which is impossible with other systems.

248 Like the throttle lever of the steam locomotive, the control lever of the single-phase locomotive may be placed in any one of its numerous notches to maintain the required speed. This facility of efficient operation over a wide range of speed and power requirements is one of the especially valuable features of the single-phase system. This difference, however, may be noted: the ability of the steam locomotive to maintain its speed continuously with heavy loads depends upon the capacity of the boiler; on the other hand, the electric locomotive has an ample supply of energy available, drawn from a large power house, and the limit of its endurance is determined by the safe temperature of the motor.

249 The question of determination of the frequency for use on single-phase railways is one of very great importance. Twenty-five cycles is in general use for power transmission purposes and has been adopted by nearly all the single-phase railroads now operating. The Midi Railway of France has adopted 15 cycles. The lower frequency permits of a marked reduction in the size of a motor for a given output, or conversely of a considerable increase in output from a motor of given dimensions and weight. Three-phase installations in nearly all cases employ approximately 15 cycles. The choice of frequency is one of the most involved, difficult and important problems now presented for solution.

SUMMARY

250 Locomotives equipped with each of the three types of motor have been in successful operation and have demonstrated their usefulness, capacity and reliability in practical railway service. The three-phase motor, having a definite constant-speed characteristic, is particularly adapted to certain conditions; but on the other hand it has a less general adaptability to the ordinary varying conditions of railway operation. The single-phase motor has a facility of voltage control which gives an efficient means of speed adjustment, and is in this particular superior to other systems. The relative weights and costs of the several types of motors, and of the locomotives designed to accommodate them, depend upon so many conditions that comparisons must necessarily be general. It will be found, however, that these differences in locomotive cost are in many cases more than offset by the cost of the other elements in the electrical system.

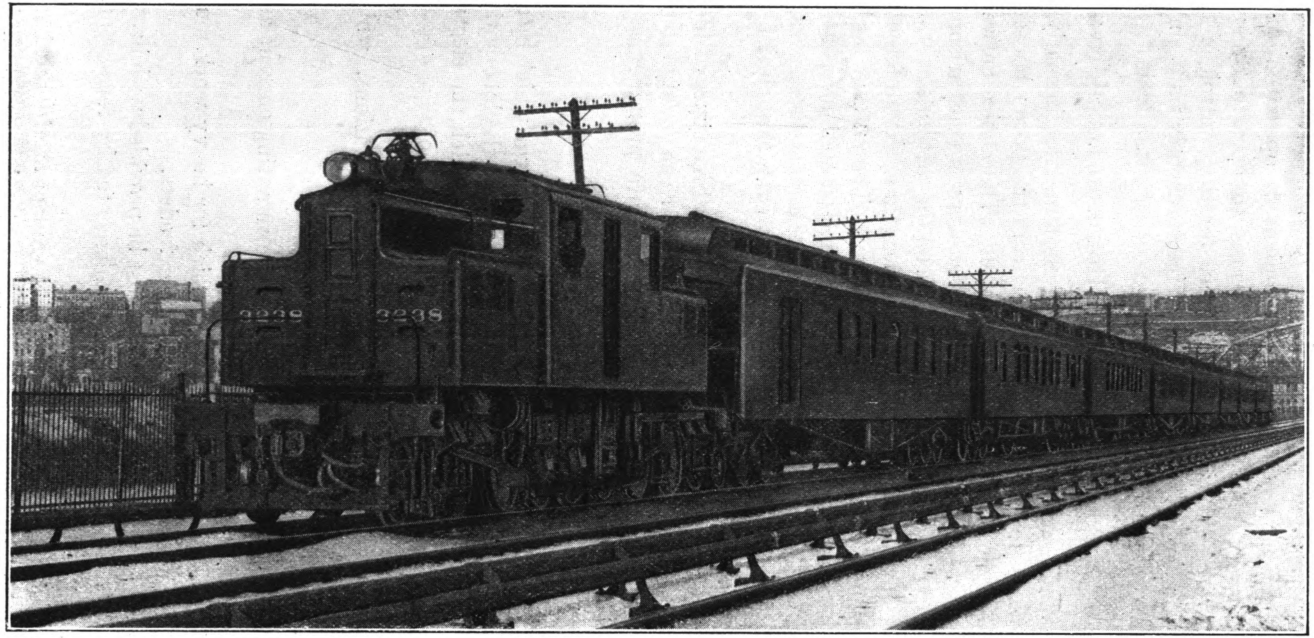


Fig. 22 New York Central and Hudson River Railroad Locomotive Drawing 20th Century Limited Train

251 The control apparatus for all types of locomotives has been developed so that it is reliable and convenient in operation. For each system a small master controller serves to operate by auxiliary means the necessary electric switches for the control of the motors of one locomotive, or to operate simultaneously as a single unit the motors on two or more locomotives or cars in a train.

Transmission of Power from Power House to Locomotive

252 The controlling factor in the cost of electrification in nearly all cases is the system for transmitting power from the power house to the locomotive, and not the locomotive itself. The choice between the several systems must, therefore, be based upon a comparison of the complete systems. The differences between the methods of transmitting power are of far greater importance than the differences between power houses or between locomotives. The current for all systems is generated in usual practice as high-tension alternating current, for the reason that electric energy can be most economically transmitted by high-tension alternating current even though it is in some cases converted into direct current.

253 The transmission systems in use for the three types of locomotives are illustrated in Appendix No. 3. Even a superficial glance at these diagrams brings several points into prominence, as follows:

THE DIRECT-CURRENT SYSTEM

254 For the direct-current locomotive the apparatus which intervenes between the alternating current-generator and the locomotive consists of a number of links or elements through which the electric energy must pass, one after the other. These consist of:

- *a* Raising transformers in groups of three.
- *b* A transmission line of three wires, sub-stations, which require attendance, containing
- *c* Transformers in groups of three, and
- *d* Rotary converters for receiving the alternating current and delivering direct current.
- *e* A third-rail contact conductor, which for heavy work must often be supplemented by copper feeders.
- *f* The track return circuit, which must be provided with heavy bonds, and in certain cases supplemented by feeders and so-called negative boosters.

255 It is necessary to maintain the alignment of the third rail within close limits both in its distance from the track rails and in its

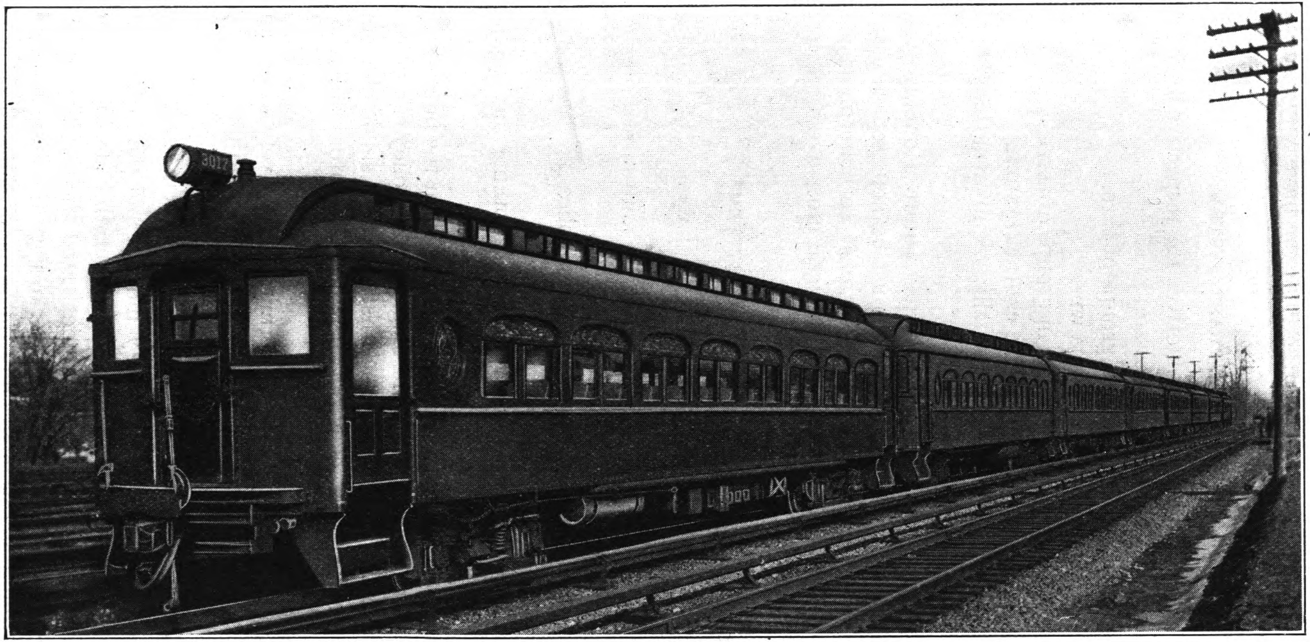


FIG. 23 MULTIPLE UNIT TRAIN IN SUBURBAN SERVICE ON NEW YORK CENTRAL AND HUDSON RIVER RAILROAD

elevation above them, as the contact shoe can have only a small range of automatic adjustment.

THE THREE-PHASE SYSTEM

256 For the three-phase locomotives the respective links between the generator and the locomotives are:

a Raising transformers in groups of three.
b Transmission line of three wires.
c Sub-station transformers in groups of three.
d Two overhead wires as the contact system.
e A track return which usually requires nothing but inexpensive bonding.

257 The two overhead trolley wires require a double system of overhead construction, as the wires must be kept separate and well insulated from one another; the two must be maintained at equal height above the track and at switches and cross-overs the construction is complicated.

THE SINGLE-PHASE SYSTEM

258 For single-phase locomotives there is:

a A raising transformer.
b A transmission line of two wires and sub-stations widely spaced, each containing
c A lowering transformer, which supplies
d A single trolley wire.
e A track return, usually requiring nothing but inexpensive bonding.

259 In certain cases where the distance from the power station is not more than 15 or 20 miles, the single-phase trolley can be supplied directly from the power house, so that only one single element, i.e., the trolley wire, intervenes between the generators and the locomotives.

260 The single trolley wire permits a relatively wide range in height, as the pantograph trolley automatically adjusts itself to the position of the trolley wire. In some cases the wire has a normal height of 22 ft., but is carried under bridges where the limit is 15½ ft.

261 The three types of railway motors, and the three respective systems for conveying power from the generating station to the locomotives, have all successfully demonstrated their ability to operate railway trains. It is not my purpose to urge the adoption of a particular system, but rather to point out some of the well-known char-

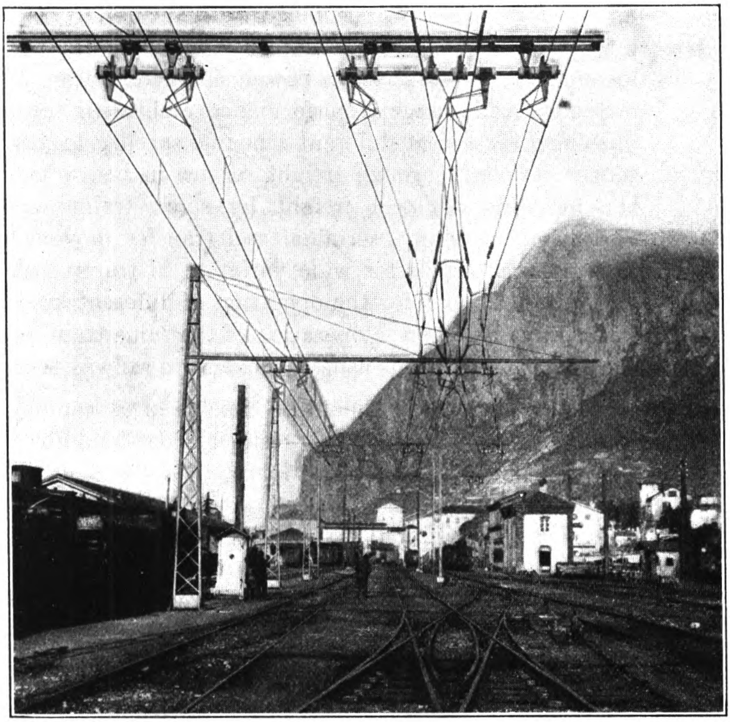


FIG. 24 OVERHEAD CONSTRUCTION ON ITALIAN RAILWAYS, LECCO-CALOLZIO LINE

acteristics of these systems which have a bearing upon their limitations and their general adaptability to railway conditions, and to urge the great gain which will result from a single universal system.

262 As the electrical manufacturing companies with which my name is associated manufacture and install all kinds of direct and alternating-current apparatus, I may be pardoned for saying that I have not permitted my judgment to be influenced by any personal material interests, and that I have treated this subject so as to give others the benefit of a long experience, acquired under circumstances most favorable to ascertaining the facts.

REQUISITES FOR A UNIVERSAL ELECTRIC SYSTEM

263 In selecting a proper electrical system for railway operation, it will probably be generally conceded that the following elements are of prime importance:

a The electric locomotives should be capable of performing the same kinds of service which the steam locomotives now perform. This will be most readily secured by electric locomotives which can practically duplicate the steam locomotives in speed and power characteristics. This includes a wide range of performance, embracing through passenger service at different schedule speeds; local passenger service; through freight service in heavy trains; the handling of local freight by short trains; and a variety of switching, terminal and transfer movements. This naturally calls for wide variation in tractive effort and in speed, both for the operation of different kinds of trains, and also for the operation of the same train under the varying conditions usually incident to railway service.

b The electric locomotive should be capable of exceeding the steam locomotive in its power capacity. It should be able to handle heavier trains and loads, to operate at higher speeds, and in general to exceed the ordinary limits of the steam locomotive in these regards. The readiness with which several electric locomotives can be operated as a single unit enables any amount of power to be applied to a train.

c The electric system should adapt itself to requirements beyond the ordinary limitations of the steam locomotive in small as well as large things. It should be adapted for use on branch lines, and for light passenger and freight service similar to that so profitably conducted by interurban electric roads, which in many cases run parallel to steam roads, not only taking away the traffic of the steam roads, but building up a new and highly profitable traffic, both in passenger and in express service.

d A universal electrical system requires that power should be transmitted economically over long distances and supplied to the contact conductor. The system should utilize the most highly perfected apparatus for the electric transmission of energy and its transformation into suitable pressures for use.

e The contact conductor in an ideal system should be economical to construct, both for the heaviest locomotives where the traffic is dense, and for light service on branch lines. It should impose minimum inconvenience to track maintenance; should give minimum probability of disarrangement in case of derailment, or in case of snow and sleet, and should in general be so placed and constructed as to give a maximum assurance of continuity of service.

264 The use now made of electricity in steam railway service has been brought about, generally speaking, through compulsion. The steam locomotive has reached its limitations and has been found unsuitable and inadequate in tunnels or in terminal service. Even where other considerations may have been controlling, the problem has usually been a specific one of electrifying a relatively small area. The problem has been solved by considering those factors which were of immediate importance, without giving weight to uniformity with other systems or of extension.

265 Now the natural course of development will be the extension of these limited zones, until after a time they meet. Then there will arise great inconvenience and expense if the systems are unlike. For the present it may be a matter of little moment whether different systems have their contact conductors in the same position, or whether the character of the current used is the same or different. As previously stated, in the early days of railroading, it was of little consequence whether the tracks of the different systems in various parts of the country were alike or unlike, but later it did make a vital difference, and the variation resulted in financial burdens which even yet lie heavily on some railways. It is this large view into the future of electrical service which should be taken by those responsible for electric railway development.

THE FUTURE OF ELECTRIFICATION OF RAILWAYS

266 The complete electrification of a railway will necessitate a rearrangement of ideas and practices in regard to operations. Coaling and watering places will not be needed; passenger trains will be differently composed, some classes being of less weight; and they will operate more frequently, thus promoting travel; other trains will be heavier than at present, or will operate at higher speeds; and branch lines, by the use of electrically fitted cars, can be given a through service not now enjoyed.

267 The movement of freight will undergo great changes, due to the fact that electric locomotives can be constructed with great excess capacity, enabling them to move longer trains at schedule speed on rising gradients.

268 The large percentage of shunting operations due entirely to the use of steam locomotives will no longer be required.

269 The railway companies can combine upon some coöperative plan for the generation of electricity, thereby effecting large savings in capital expenditures; and can utilize their own rights of way for the transmission of the current, not only for the operation of trains but for many other useful purposes.

270 Notwithstanding the fact that great strides have already been made in cheapening the cost of generating electricity by steam engines, I foresee, from the progress made in the development of gas and oil engine power, a still further reduction in cost which will accelerate the work of electrifying existing railways.

271 One important aspect of this great question will engage the thoughtful consideration of every government, namely, the military necessity for uniform railway equipment in time of war.

272 There will be serious difficulties to surmount in the selection of a general system. There naturally will be arguments in favor of one or another of the systems now in use and the inclination of those who have adopted a particular system to advocate its general use. There will be enthusiastic inventors, and there will be many advocates of the common view, namely, that there is room for several systems and that each system will best meet the requirements of a particular case. There will be those who give undue weight to some feature of minor importance, such as a particular type of motor or of locomotive, instead of giving a broad consideration to the whole system, and recognizing that, in the general problem of railway electrification, facility and economy in transmitting power from the power house to the locomotive are of controlling importance.

273 Were there now only one system to be considered, there would be a concentration of the energy of thousands on the perfecting and simplifying of the apparatus for that system, to the advantage of railway companies and of manufacturers.

274 In conclusion, I can only repeat, and earnestly recommend to the serious consideration of railway engineers and those in authority, the pressing need of determining the system which admits of the largest extension of railway electrification and of a prompt selection of those standards of electrification which will render possible a complete interchange of traffic in order to save expense in the future and to avoid difficulties and delays certain to arise unless some common understanding is arrived at very shortly.

APPENDIX No. 1

THE SINGLE-PHASE SYSTEM ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

275 The most important installation of single-phase apparatus is that of the New York, New Haven & Hartford Railroad, leading out of New York City. Practically all the railroad service between New York and Boston, as well as the New England States, is over the four tracks of this railroad. The trains pass into the Grand Central Station in New York City over the lines of the New York Central & Hudson River Railroad, which is electrically equipped with the third-rail system for operation by direct current at 650 volts. Selection of the system for the New Haven railroad was restricted by the necessity of operating the New Haven trains over the New York Central tracks; but the decision was in favor of the single-phase system, notwithstanding the limitation that the locomotives must operate successively both by single-phase current and direct current.

276 The trains of the New Haven system leaving the Grand Central Station pass over 12 miles of the tracks of the New York Central system, operating from the third rail by direct current. They then pass to the New Haven tracks at full speed, receiving alternating current at 11,000 volts from the overhead trolley wires which extend 21 miles to Stamford, a total distance of 33 miles from New York, this being the end of the initial installation of the single-phase system.

277 The power house is located near the Stamford end of the electrified section and contains four 11,000-volt turbo-generators having an aggregate capacity of over 16,000 kw. The current passes directly from the generators to the trolley wires, as illustrated in Fig. 35 and in the last diagram of Fig. 36.

278 The overhead trolley system consists of a steel contact trolley wire suspended every 10 ft. from a copper trolley wire, which in turn is suspended at intermediate points from two steel catenary cables by triangular-shaped hangers. These cables are supported upon insulators resting upon steel bridges spaced at distances of 300 ft. along the right of way. The construction is shown in Fig. 18 of the paper.

279 As in general there are four tracks and in some cases more, the comparatively light steel bridges are made to span the right of way and to carry as many sets of the trolley conductors as there are tracks. Stronger bridges to which the catenary cables are anchored are located about every two miles. At certain points these anchor bridges are utilized for supporting the block signals and also to carry oil circuit breakers which permit the trolley wires to be sectionalized for service operation or in emergencies. Normally all the trolley wires and the supporting cables over all the tracks are connected together electrically and also to the source of supply at the power house.

280 There are 41 locomotives in regular operation, and also four motor cars with six trail cars operating on the multiple unit system in suburban service. The alternating current is taken from the overhead trolley wire by a pantagraph which presses a shoe against the wire. The direct current on the New York Central zone is obtained from the third rail by means of ordinary sliding contact shoes. Both the pantograph and the contact shoes are manipulated by compressed air. The locomotive is described in Par. 291.

281 For reasons of economy in operation the locomotives were built under the requirement that each should be capable of hauling a 200-ton train from New York to New Haven, making all station stops in accordance with the regular schedules, or an express train of 250 tons, and that the locomotives should be so arranged that two or more could be operated by a single engineer for the movement of heavier trains. The particular size selected permits about 75 per cent of the trains to be operated by a single unit.

TABLE 23 RECORD OF SINGLE-PHASE SERVICE

NEW YORK, NEW HAVEN & HARTFORD RAILROAD FOR 12 MONTHS

	Total Miles Run	No. Locomotive Delays	Miles Run per Locomotive Delay	No. of Power House Delays	No. of Line Delays
1909					
April	146,189	9	16,243	..	3
May	155,551	25	6,222	1	3
June	166,759	14	11,911	..	4
July	183,434	13	14,110	..	2
August	177,714	14	12,694	..	5
September	189,656	14	13,547	..	1
October	174,400	11	15,854	1	4
November	173,370	10	17,337	..	1
December	167,808	23	7,296	..	3
1910					
January	163,274	28	5,831	..	2
February	138,929	12	11,577	..	1
March	156,901	12	13,075	..	1

282 During the past year, the electric service has surpassed in efficiency all records previously obtained on this division with steam locomotives. The actual figures are given in Table 23, which covers the movement of passenger trains over the 12 miles of third-rail operation and 21 miles of single-phase operation, for which 41 locomotives, that have been used from 22 to 33 months, were available.

283 The early fears as to difficulties in commutation have been dispelled by the records of performance, as many of the motors have operated over 100,000 miles without turning or even sandpapering the commutators, and the brushes show an average life of 40,000 to 45,000 miles.

284 The average number of miles run per locomotive delay during the year exceeds 12,000, equivalent to a dozen trips between New York and Chicago, or thirty trips between London and Glasgow.

285 The locomotive delays (many of which only slightly exceeded one minute duration) include not only those from electrical causes, but from mechanical

defects as well, such as loose tires, burst airhose, hot journal boxes, frozen steam hose, etc. A comparatively large number of delays in December and January were due to the very severe weather and the unusual amount of snow and ice. These locomotives have been making regularly an average of about four and one-half trips of 33 miles per day, hauling trains 25 to 50 per cent heavier, or even more in the case of express trains, than the locomotives were guaranteed to handle. Most of the locomotives have run about 100,000 miles, but there is seldom more than one (which is 2½ per cent of the whole number) out of service for repairs, a record said by the officials of the company to be much better than for the steam locomotives which were replaced. These officials also say that the cost of maintenance per mile and the number of miles run per electric locomotive are far more favorable than with steam locomotives, even with the present very short run of 33 miles.

286 The cost of maintenance of the distribution system is relatively small compared with that of the low-voltage third-rail system. The delays due to the transmission lines and overhead construction, though few in number, include those brought about by extraordinary conditions, such as steam from switch engines and by wrong operation of switches.

287 The heaviest traffic on the New York division of the New Haven road, and the occasion on which delays would be most deplored, is on the day of the annual intercollegiate football game at New Haven. The service on this day for 1908 and 1909 was as follows:

	1908	1909
Regular trains	128	126
Special trains	30	29
Total trains	158	155
Number of train delays	2	0
Total duration of delays	17 min.	

288 In considering the capability of the single-phase system for continuous performance, the record of the six single-phase locomotives in service at the St. Clair Tunnel of the Grand Trunk Railway is worthy of mention. These locomotives have now been running two years and have made about 70,000 miles each, averaging about 100 miles per day, or 25 trips of 4 miles. It has not been necessary to use a steam locomotive since the regular electric service was started (May 1908) and during the last 12 months the service has been responsible for but one train delay, of eight minutes. The locomotive is described in Par 292.

APPENDIX No. 2

DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

289 The locomotives on which data are given were built for heavy railway service. They are for passenger service and for combined passenger and freight, and include locomotives for direct current, three-phase current, and single-phase alternating current, and others adapted for operation on either single-phase alternating current or direct current.

290 A brief description of these locomotives follows, including mention of some of their notable features.

LOCOMOTIVES OF THE WESTINGHOUSE ELECTRIC & MFG. CO.

291 Referring to Table 24, the first column covers locomotives built for the New York, New Haven & Hartford Railroad, for operation on their electrified zone between New York and New Haven. The electrical system demanded that the locomotives be capable of operation both on single-phase and direct current. There are 41 of these locomotives in operation. A gearless concentric motor for each driving axle is mounted on a quill flexibly connected to the driving wheels. The dead weight on the axles is thus reduced to a minimum. Two of these locomotives are shown attached to the train in Fig. 18 of the paper.

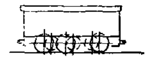
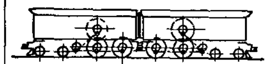
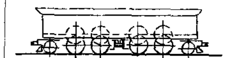
292 The second column covers locomotives built for the Grand Trunk Railway for operation in the St. Clair Tunnel under the St. Clair River. These locomotives are designed for operation with single-phase current only. They are handling the entire freight and passenger traffic through the tunnel. A report of the operation of these locomotives is given in Par. 288, Appendix No. 1. The locomotive is shown in Fig. 25.

293 The third column covers locomotives built for the Pennsylvania Railroad for operation in their New York tunnel. They are for passenger service only and operate on direct current at 600 volts on the conductor. The first locomotive has been run 17,000 miles on test. The center of gravity of these locomotives is high, as the motor is mounted well above the driving axles. The transmission from motor to wheels is by cranks and connecting rods. These parts are protected from possible damage due to short circuit by interposing between the armature and its shaft a friction clutch which will slip before damaging stresses are imposed on the transmission. The motors are the largest railway motors ever built and are provided with commutating poles, making possible the use of a shunted field control which is applied to these locomotives. The locomotive is shown in Figs. 26 and 27.

294 The fourth column covers a locomotive built for the New York, New Haven & Hartford Railroad for use in high-speed freight and medium-speed passenger service. It also is fitted for operation both with single-phase and direct-current.

TABLE 24 DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

BUILT BY THE WESTINGHOUSE ELECTRIC & MFG. Co.

					
Built for	New Haven	Grand Trunk St. Clair Tunnel	Pennsylvania	New Haven	New Haven
Electric system	A.C., D.C.	A.C.	D.C.	A.C., D.C.	A.C., D.C.
Service	Passenger	Frt. & Pass.	Passenger	Frt. & Pass.	Frt. & Pass.
First placed in service	July 1907	February 1908	17,000-mile test	3000-mile test	building
No. in service or on order May 1910	41	6	24	1	1
No. motors per locomotive	4	3	2	4	2
Armature diameter, inches	39½	30	56	39½	76
Core length, including vent opening, inches	18	14¾	23	13	13
Weight one motor, lb	16,420	15,660	45,000	19,770	41,600
Weight all motors on locomotive	65,680	46,980	90,000	79,080	83,200
Weight all electrical parts	110,400	58,400	127,200	130,000	135,000
Weight all mechanical parts	94,100	73,600	204,800	130,000	125,000
Weight complete locomotive	204,500	132,000	332,000	260,000	260,000
Weight on driving wheels	162,000	132,000	207,800	180,000	180,000
Weight complete locomotive for A.C. operation	196,000	132,000	D.C.	241,000	240,000
Max. guar't'd speed, miles per hr.	about 86	30	about 80	45	45
Feature limiting speed	track	armatures	connecting rod	armatures	armatures
Max. tractive effort	19,200	43,800	69,300	40,000	40,000
Loco. wt. in excess of 18% adhesion Max. T.E., A.C. operation	88,700	none	none	18,500	17,500
Designed for trailing load, tons	250	500	550	1500 freight 800 pass.	1500 freight 800 pass.
Balance speed on level with above load	about 75	about 25	60	35 freight 45 pass.	35 freight 45 pass.

It has been run approximately 3000 miles in test service, actually hauling regular freight trains, including the steam locomotives, over the electrified section of the railroad on the normal schedules for the movement of these trains. A pinion at each end of the motor meshes with a flexible gear whose center is rigidly secured to the quill surrounding the axle, the flexible gear overcoming the difficulties in securing tooth alignment and division of load which are liable to occur when rigid twin gears are used. It is the only electric locomotive equipped with spur-geared motors which are bolted rigidly to the spring-supported parts of the locomotive. Each driving wheel is driven through helical springs, the arrangement being such that the driving wheel has practically free vertical play. The locomotive has two trucks, the drawbar pull being transmitted

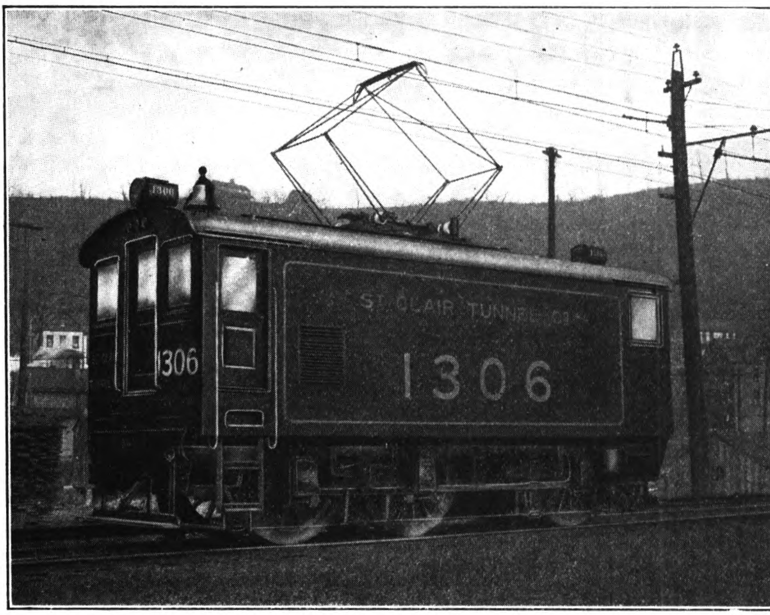


FIG. 25 SINGLE-PHASE LOCOMOTIVE FOR PASSENGER AND FREIGHT SERVICE IN ST. CLAIR TUNNEL OF GRAND TRUNK RAILWAY

through the truck frames. The body is spring-mounted on friction plates in place of being carried on truck center pins in the usual manner. It is an exceptionally easy riding machine with very low rolling friction. The performance has b en satisfactory, and a speed of 40 miles per hour was attained on level track with a 1600-ton train. See Figs. 28 and 29.

295 The fifth column covers a locomotive for the same railroad and service as that just described. The comparison between geared and connecting-rod motors for identical service is a very interesting feature of this development. The weights given in both the fourth and fifth columns are those on which locomotives of these types would generally be built. The actual locomotives are somewhat

heavier, due to particular features of design not inherent in the type. The effect on the connecting rods and pins of the pulsating torque of a single-phase current is avoided by the introduction of a flexible connection between the armature and its shaft. This locomotive has not been tested.

296 These last two locomotives were ordered by the New Haven road to demonstrate the practicability of electric traction for freight service and to assist in determining the most suitable kind or type of locomotive.

LOCOMOTIVES OF THE GENERAL ELECTRIC COMPANY

297 The first column of Table 25 covers locomotives built for the New York Central & Hudson River Railroad for operation on the electrified zone of the New York City terminal. Forty-seven of these locomotives are in use, the first having been put in operation in July 1906. They are used for passenger service only, and operate on direct current at 600 volts. The mechanical equipment of this locomotive consists of a main driving wheel base with four driving axles and a four-wheel guiding truck at either end. The motor is of the bi-polar gearless type, the armature being mounted directly on the driving axle, and the mechanical structure of the locomotive forming a portion of the magnetic circuit of the motors. The characteristic feature of the locomotive is the simplicity of its electrical and mechanical construction, which contributes to its high efficiency and low maintenance cost. The locomotive is shown in Figs. 22 and 30.

298 The second column of Table 25 covers locomotives built for operation at the Detroit River Tunnel. These are to be used for both freight and passenger service between Detroit, Mich., and Windsor, Ont., and will be operated at 600 volts, direct current. The running gear consists of two trucks connected together with a massive hinge so as to form a single articulated wheel base, and buffers carried on the outer end frames of the trucks. The motor is of the direct-current geared type with commutating poles and is interesting as the first application of the commutating pole motor to this class of service. Twin gearing is used between the motor and driving axle, and consists of a pinion at each end of the armature shaft and a corresponding gear on the axle. The use of twin gearing relieves the armature shaft of torsional strains and maintains the parallelism of the shaft and axle. Five of these locomotives have been built and are awaiting completion of the tunnel. While they are not in actual operation, extensive tests made on a test track in hauling and accelerating freight trains up to 1500 tons in weight have proved that this type is very satisfactory for the service.

299 The third column covers locomotives built for the Baltimore & Ohio Railroad for operation of both freight and passenger service through the Baltimore Belt Line Tunnel. Two of these locomotives are in use and operate on direct current at 600 volts. The general design is similar to the Detroit Tunnel locomotive described above and the same type of motors are used, but the motors are geared for higher speed in order to meet the speeds required by passenger service on the relatively lighter grades of the Baltimore Tunnel.

300 The fourth column covers locomotives built for the operation of freight and passenger trains through the Cascade Tunnel of the Great Northern Railway. These locomotives are designed for three-phase operation at 25 cycles and 6600 volts on the trolley. The mechanical structure consists of an articulated wheel base similar to that of the Detroit River Tunnel locomotive described above. The a motor is three-phase induction motor with external secondary resistance and

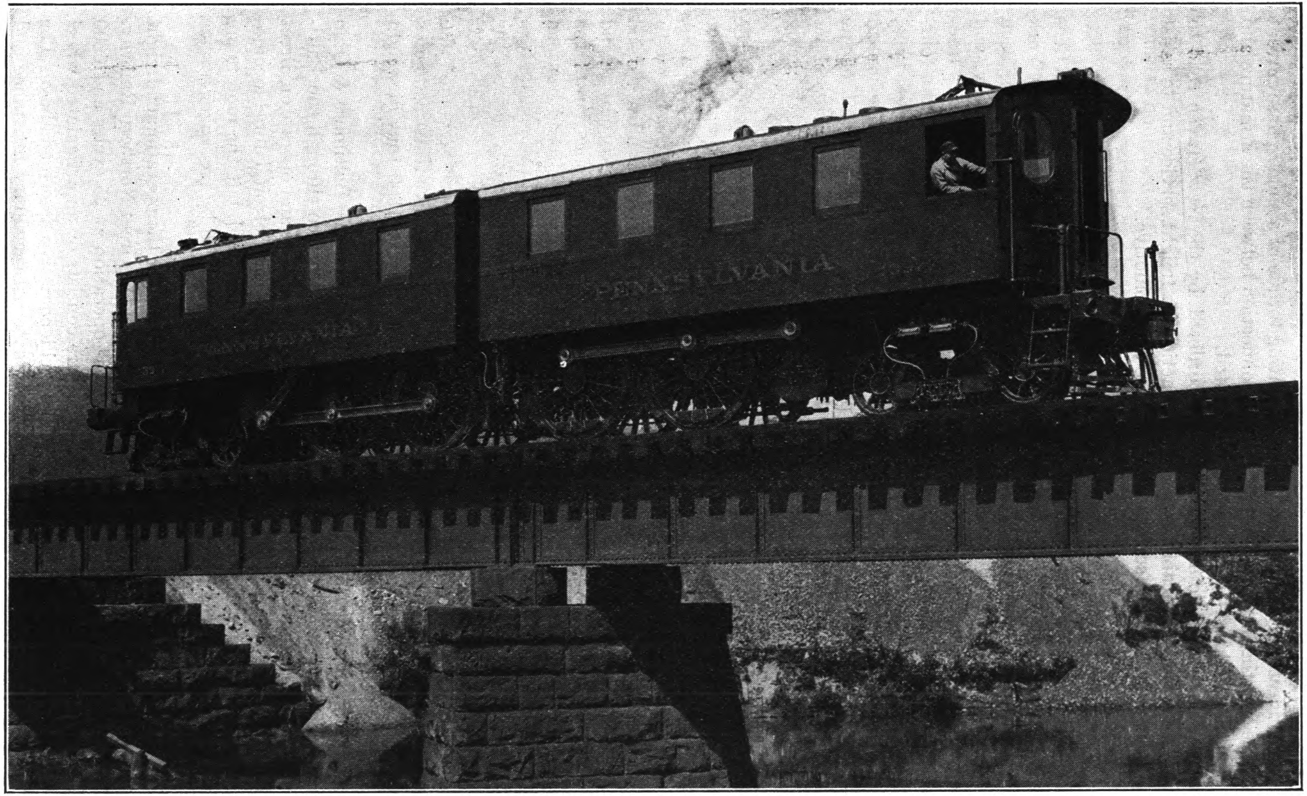


FIG. 26 PENNSYLVANIA DOUBLE ARTICULATED LOCOMOTIVE FOR THE NEW YORK TUNNEL SERVICE

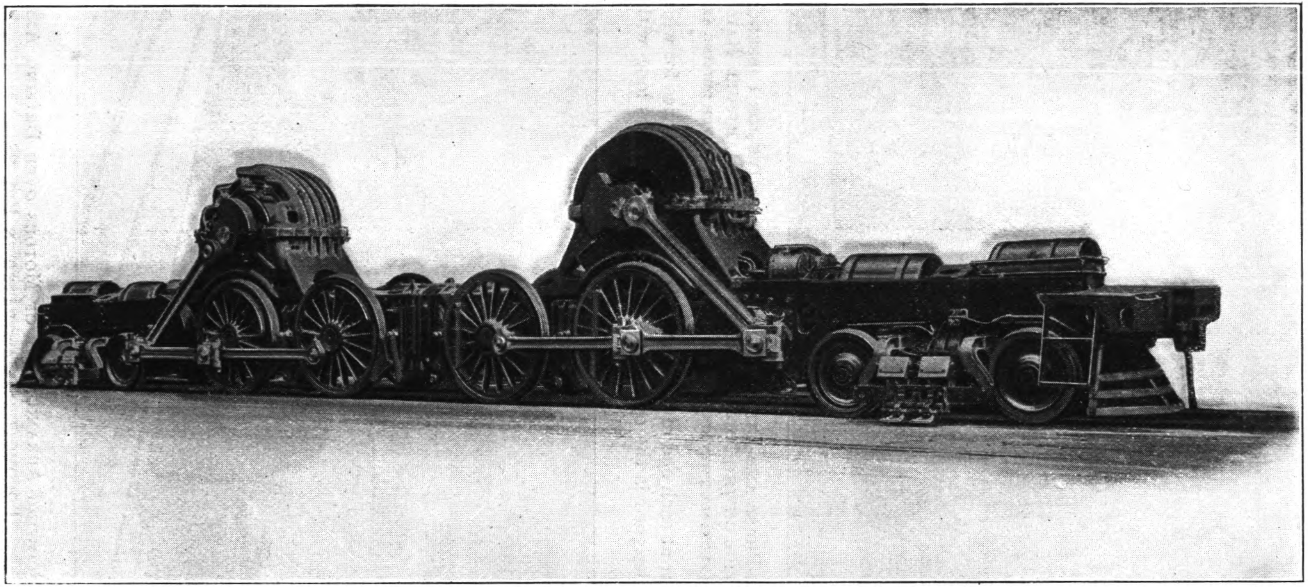


FIG. 27 UNDER FRAMES, MOTORS AND DRIVING MECHANISM OF PENNSYLVANIA DOUBLE ARTICULATED LOCOMOTIVE FOR NEW YORK TUNNEL SERVICE

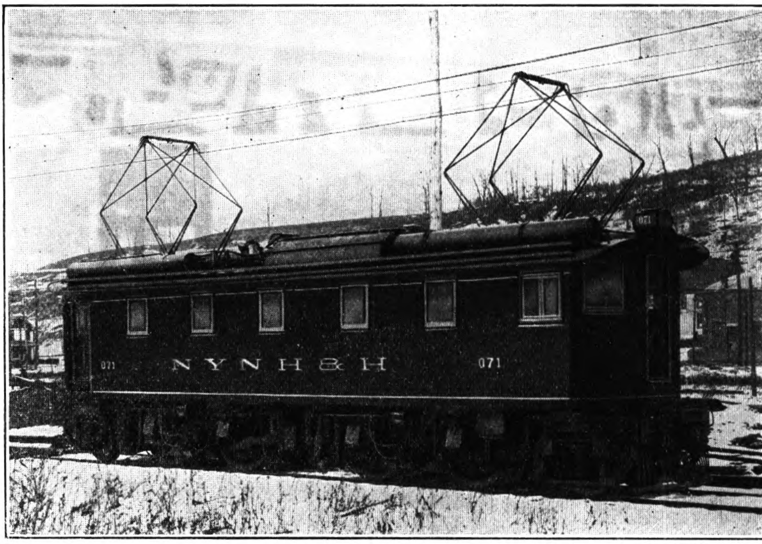


FIG. 28 SINGLE-PHASE AND DIRECT-CURRENT LOCOMOTIVE FOR PASSENGER AND FREIGHT SERVICE ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

MOTORS WITH FLEXIBLE TWIN SPUR GEARS ARE PLACED DIRECTLY OVER DRIVING AXLES

fitted with a gear at each end of the armature shaft. The service for which they are ultimately designed is the operation of a division 57 miles long with ruling

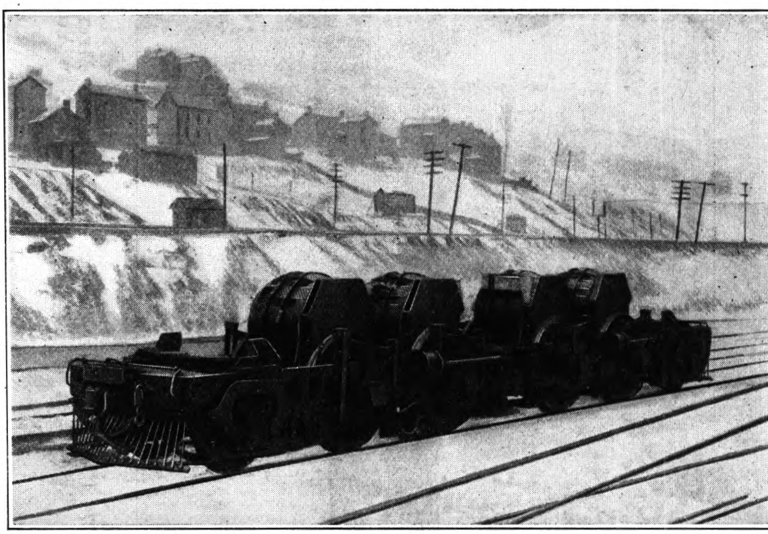
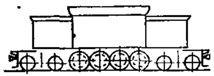
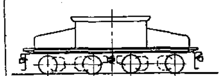
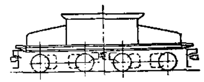
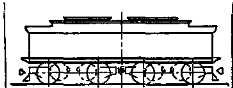
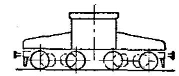


FIG. 29 VIEW SHOWING ARRANGEMENT OF MOTORS OVER DRIVING AXLES FOR LOCOMOTIVE ILLUSTRATED IN FIG. 28

TABLE 25 DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

BUILT BY THE GENERAL ELECTRIC COMPANY

					
Built for	N. Y. C. & H. R. R. R.	Detroit River Tunnel	B. & O. R. R.	Great Northern	Paris-Orleans
Electric system	D.C.	D.C.	D.C.	3-phase	D.C.
Service	Passenger	Frt. & Pass.	Frt. & Pass.	Frt. & Pass.	Passenger
First placed in service	July 1906	tests completed	March 1910	July 1909	1899
No. in service or on order May 1910	47	6	2	4	11
No. motors per locomotive	4	4	4	4	4
Armature diameter, inches	29	25	25	35¾	23½
Core length, including vent opening, inches	19	11½	11½	16¼	12
Weight one motor, lb	18,150	10,560	10,560	15,000	8,855
Weight all motors on locomotive	72,600	42,240	42,240	60,000	35,420
Weight all electrical parts	91,200	54,000	54,000	109,000	42,500
Weight all mechanical parts	138,800	146,000	130,000	121,000	67,500
Weight complete locomotive	230,000	200,000	184,000	230,000	110,000
Weight on driving wheels	141,000	200,000	184,000	230,000	110,000
Weight complete locomotive for A.C. operation	D.C.	D.C.	D.C.	230,000	D.C.
Max. guar't'd speed, miles per hr.	75	30	55	30	45
Feature limiting speed	track	armature	armature	armature	armature
Max. tractive effort	47,000	67,000	61,000	77,000	37,000
Loco. wt. in excess of 18% adhesion Max. T.E., A.C. operation	none	none	none	none	none
Designed for trailing load, tons					
Freight		900 on 2% grade	850 on 1½% grade	500 on 2.2% grade	
Passenger		600 on 2% grade	500 on 1½% grade		
Balance speed on level with above load	435 63	Freight 20.5 Pass. 22	Freight 26 Pass. 30	15	300 32

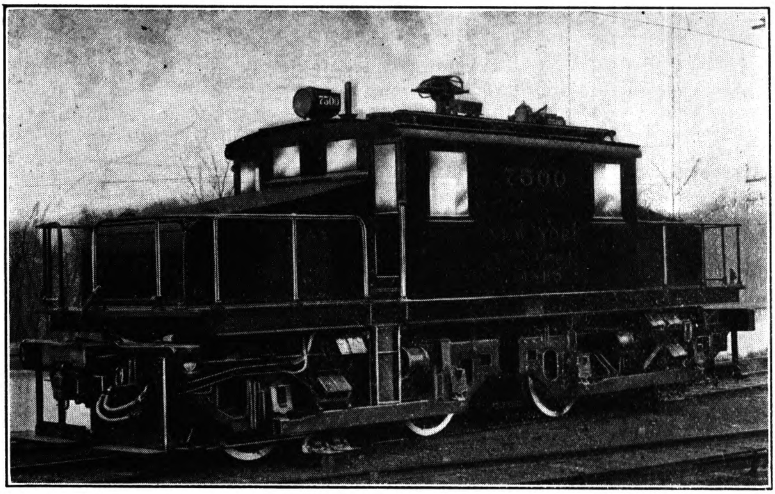


FIG. 30 ELECTRIC LOCOMOTIVE ON THE NEW YORK CENTRAL & HUDSON RIVER RAILROAD

grades of 2.2 per cent and an average grade of 1.55 per cent. Four of these locomotives are in service and it may be of interest to note that they were involved in the disastrous avalanche of March 1, 1910, which swept through the electrified yards at Wellington, Wash. The locomotive is shown in Fig. 31.

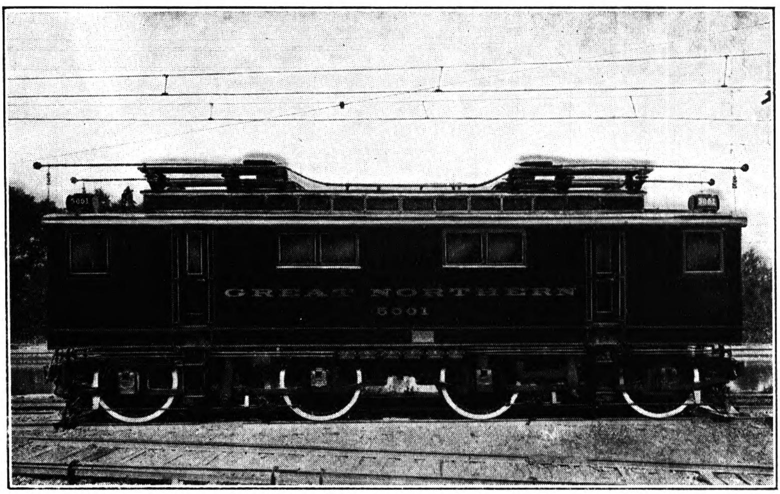


FIG. 31 ELECTRIC LOCOMOTIVE ON THE GREAT NORTHERN RAILWAY

301 The fifth column covers locomotives built for the Paris-OrleansRailway, for use in hauling passenger trains from the Austerlitz Station to the Quai d'Orsay. They are designed for operating on 600 volts, direct current. These locomotives are historically of interest, the first one of them having been delivered in 1899, and twelve being now in service. Each locomotive has two independent trucks, each truck equipped with two geared motors, and carrying weight of cab and platform on the center pin with draft gear and buffer attached to this platform. This represents a type of locomotive of which a large number have been built, and which has proved highly satisfactory for light and medium classes of service.

APPENDIX No. 3

COMPARISON OF SYSTEMS OF ELECTRIFICATION

302 The salient features of the three systems of railway electrification are presented in a number of diagrams so arranged as to permit of a ready comparison between their essential characteristics, particularly in the circuits and apparatus which transmit the power from the power station to the locomotive.

303 The perspective sketches, Figs. 32 to 35, show the commonly used types of apparatus and circuits in a simple and elementary way, as only a single generator and a single sub-station, containing but one group of units, are shown, and auxiliaries such as switchboard apparatus are altogether omitted.

304 Fig. 32, showing the direct-current system, illustrates the alternating-current generator, the three raising transformers, the three-phase transmission circuit, the three sub-station lower transformers, and the rotary converter which supplies direct current to the third-rail contact system.

305 Fig. 33, illustrating the three-phase system, is similar to Fig. 32 up to the point where the power passes the sub-station transformers. Power is then delivered directly to the contact system, consisting of two overhead trolley wires, shown suspended from supporting cables in accordance with the commonly used catenary construction.

306 Fig. 34, presenting the single-phase system, has a similarity to the preceding sketch of the three-phase system, Fig. 33, and may be derived from it by simplifying its several elements. Single transformers instead of groups of three are found in the power house and sub-station. The transmission has two wires instead of three and there is but one trolley wire instead of two.

307 Fig. 35 shows the single-phase system where the distances are moderate and the generator can supply current directly to the trolley wire at 11,000 volts, thereby eliminating the high-tension transmission circuit and the sub-stations. This is the method employed in the single-phase installation on the New Haven system.

DIAGRAMS OF TRANSMISSION CIRCUITS AND SUB-STATIONS

308 Fig. 36 shows the arrangement of transmission lines and contact circuits and the relative number and location of sub-stations for each of the three systems.

309 The direct-current sketch, Fig. 36, shows the three-phase transmission line running from the power house to the sub-stations, which contain step-down transformers and rotary converters for changing the high-potential alternating current to low-potential direct current. It also shows the third rail supplemented by an auxiliary conductor or feeder. The track serves for the return circuit.

310 In a certain typical case it was found that the sub-stations should be approximately eight miles apart for a pressure of 600 volts in the direct-current system. If direct current were used at a pressure of 1200 volts, half of the sub-stations could be omitted.

311 The distances above mentioned are found to be proper for a particular case and the diagram is intended simply to show approximately the relative number of sub-stations required in the several systems. The actual distances in other cases may be more or less than those given. In the several systems employing a transmission line the distance may obviously be extended to include a greater number of sub-stations than are shown.

312 The three-phase sketch, Fig. 36, shows the three-phase transmission line and sub-stations containing transformers only, for reducing the high-potential alternating current to low-potential alternating current for use on the double overhead trolley system with track return. The sub-stations are spaced the same distance apart as those in the direct-current system. This arrangement of sub-stations is for 3300 volts on the trolley. With 6600 volts on the trolley, half of the sub-stations would be omitted.

313 The larger single-phase sketch, Fig. 36, shows a single-phase transmission line running to sub-stations containing transformers only, to reduce the high-potential alternating current of transmission to a suitable potential, 11,000 volts, for use on the single overhead trolley with track return.

314 The smaller single-phase sketch shows a single-phase line which is not too long to prevent the entire system from being fed directly from the generators without the intervention of transmission line or transformers between the generators and the trolley circuit. This sketch shows the method employed on the New Haven system.

315 In thickly populated districts congested with traffic, the generating stations, of which there should be not less than two in order to minimize interruptions to traffic, should probably be located at junction points or places demanding the greatest power and at distances not exceeding thirty or forty miles. With such a disposition of power houses, the overhead trolley wires will usually be sufficient for the supply of current. In like manner, where the traffic is not so heavy, the power houses can be placed at greater distances, bearing in mind, however, that the increase in traffic may subsequently demand intermediate power houses or sub-stations. In cases where power stations are long distances apart, the single trolley wire should probably be supplemented by an additional circuit in order to guard against interruptions due to defect in the trolley wire, and to give a sufficient supply of power for any contingency.

COMPARATIVE LOSSES, SHOWN IN FIG. 37

316 Fig. 37 shows the comparative losses between the generators and the locomotives for each of the three systems, based on a class of service where the input to the locomotives by the several systems is practically the same.

317 As some kinds of service render one type of motor with its auxiliary apparatus and control more efficient, while under other conditions it may be less efficient, this variable element has been eliminated by assuming the same power delivered to each locomotive as a basis for a general comparison of the transmission losses.

318 The total height of each column in the diagram indicates the total power delivered by the power house in the system designated. The height of the long portion at the lower part of each column indicates the amount of power which reaches the locomotive.

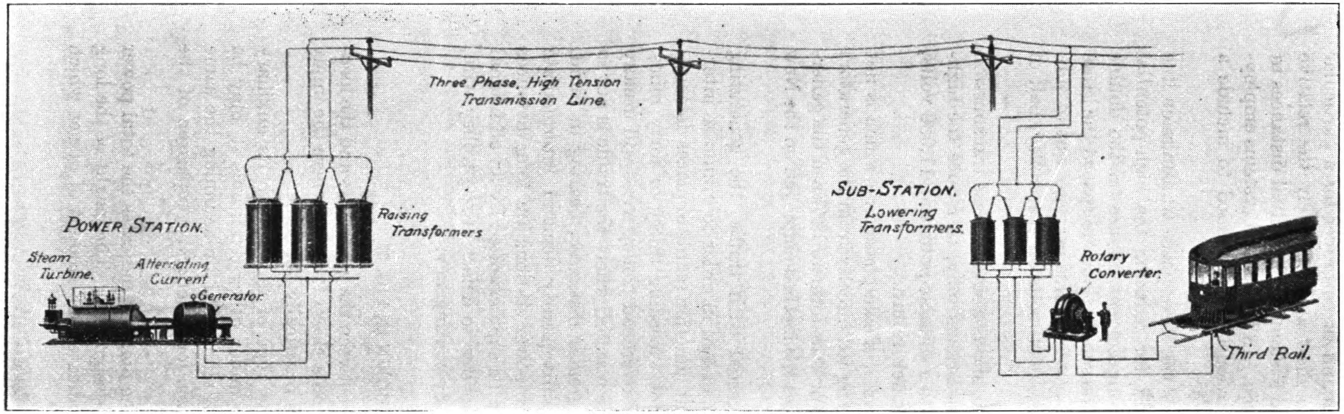


FIG. 32 DIRECT-CURRENT RAILWAY SYSTEM

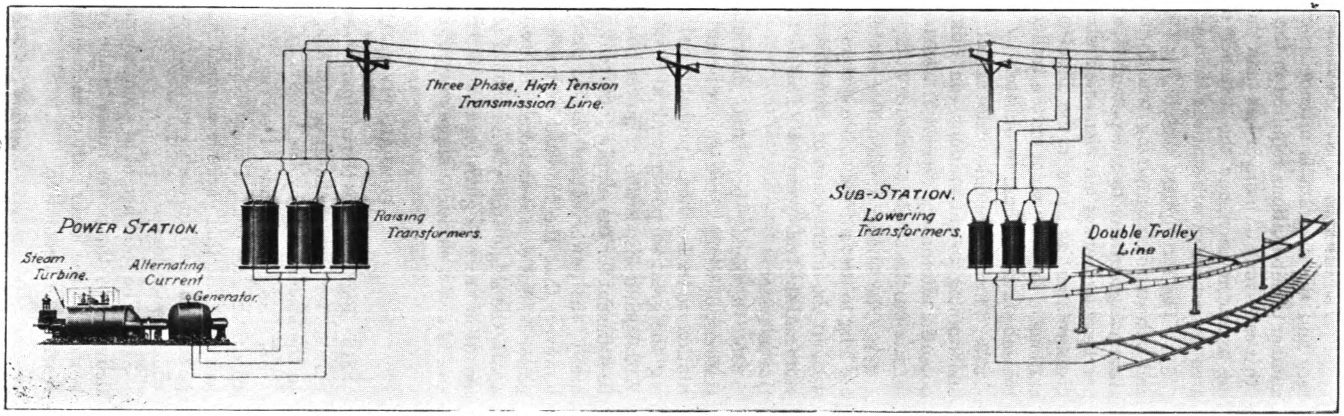


FIG. 33 THREE-PHASE RAILWAY SYSTEM

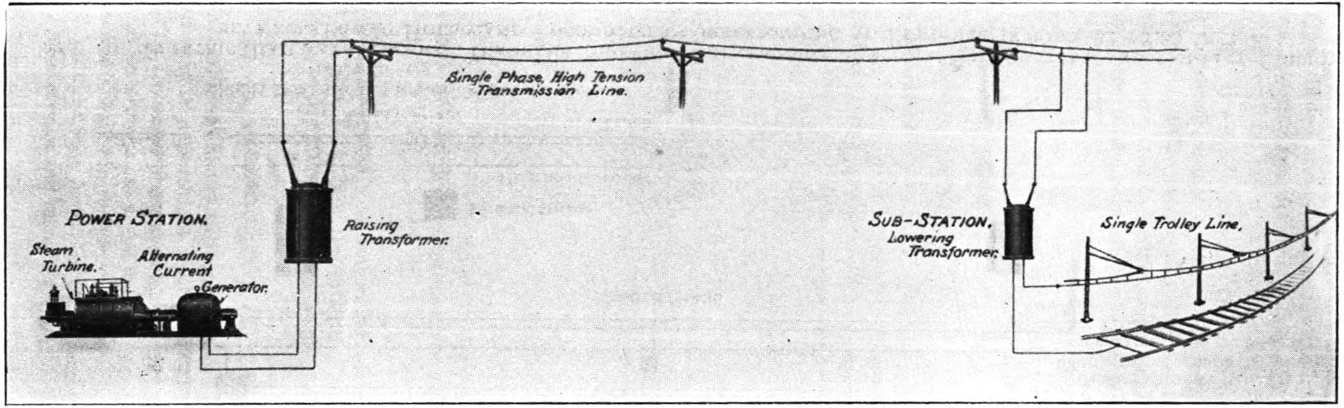


FIG. 34 SINGLE-PHASE RAILWAY SYSTEM

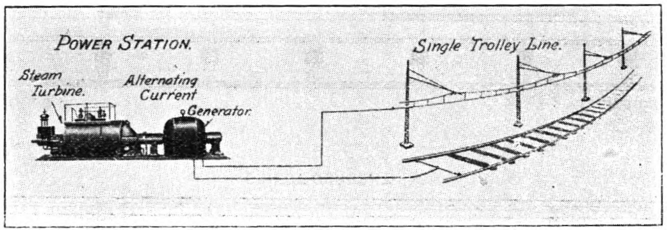


FIG. 35 SINGLE-PHASE RAILWAY WITHOUT TRANSMISSION SYSTEM

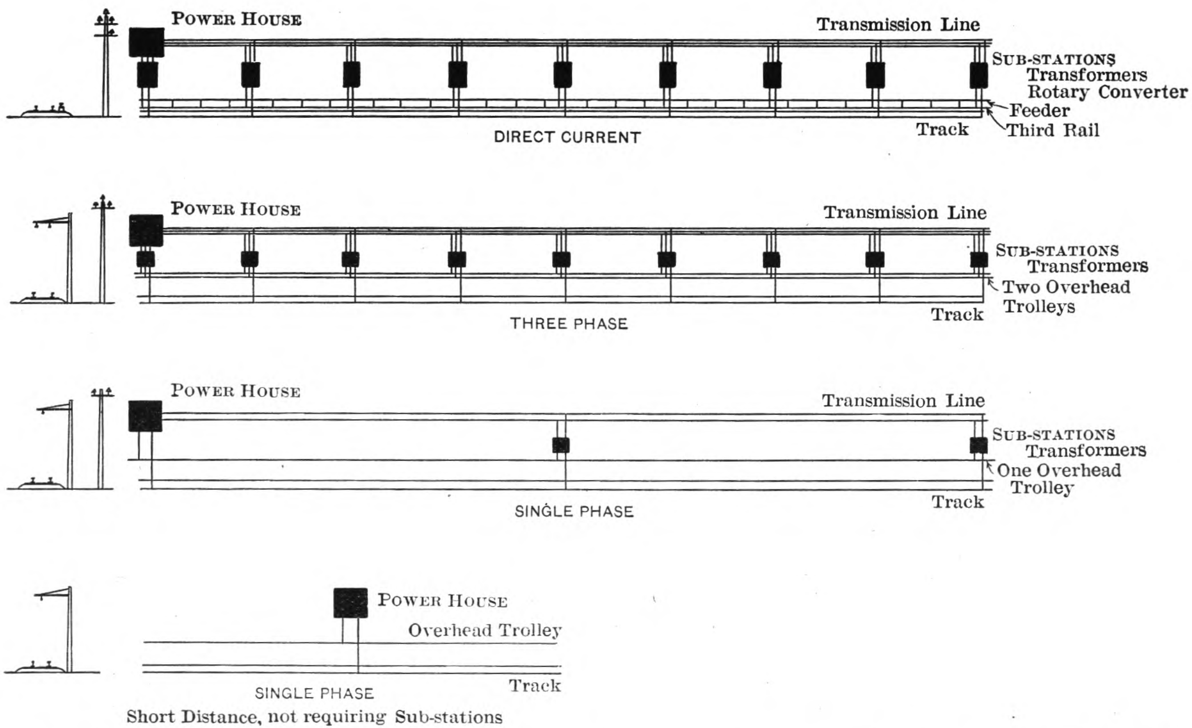


Fig. 36 Electric Railway Systems. Diagrams Showing Transmission Circuits, Sub-Stations and Contact Circuits between Power House and Locomotives Corresponding to Sketches in Figs. 32 to 35

319 The loss between power station and the locomotives is represented by the upper shaded areas. The respective losses in raising transformers, transmission line, lowering transformers, rotary converters and the contact line (comprising trolley or third rail with track return) are segregated.

320 It will be noted that the large losses in the rotary converters appear only in the direct-current system. The larger single-phase column shows the losses where the distances are such that it is necessary to use a transmission line and transformers. The smaller single-phase column represents the trolley wires connected to the generators without any intervening transmission line or transformers. The loss of power between power house and locomotives is relatively

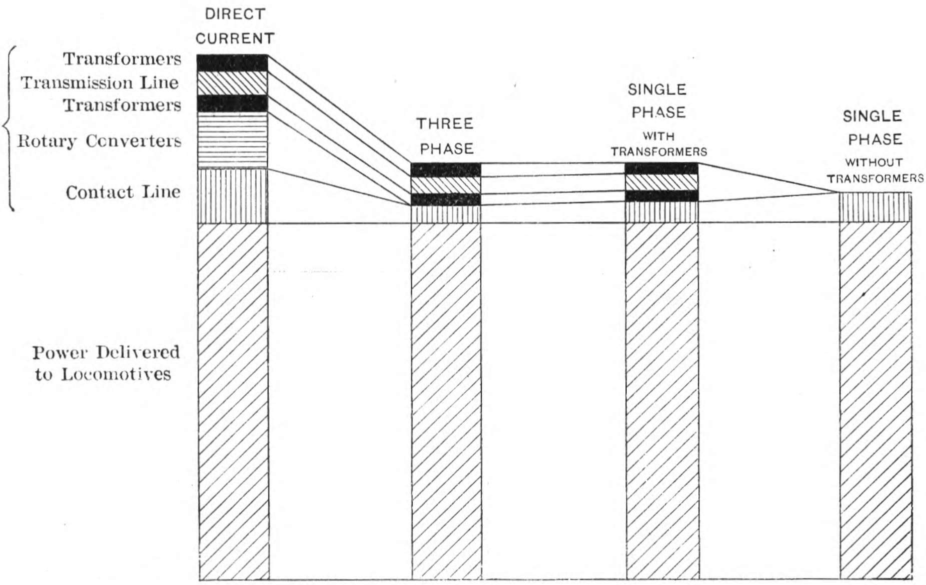


Fig. 37 Showing Comparative Losses Between Power House and Locomotives

small as compared with that in any of the other systems. This is the condition on the New York, New Haven & Hartford Railroad, where the power house is distant nearly 20 miles from one end of the line.

COMPARATIVE FIRST COSTS, SHOWN IN FIG. 37

321 Fig. 37 shows the comparative estimates prepared a few months ago of first cost in a particular case for electrification by the direct-current system and by the single-phase system. In the preparation of these estimates the three-phase system was not called for and as no estimate covering it has been prepared, it is not included in the present comparison. The estimates cover a single track line 100 miles long involving both freight and passenger traffic in both through and local service and include twenty locomotives.

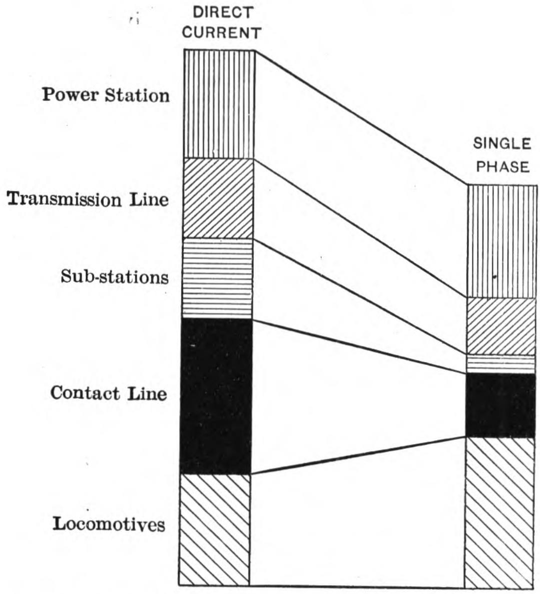


FIG. 38 COMPARATIVE FIRST COSTS FOR DIRECT-CURRENT AND SINGLE-PHASE SYSTEMS IN A PARTICULAR CASE OF 100-MILE SERVICE

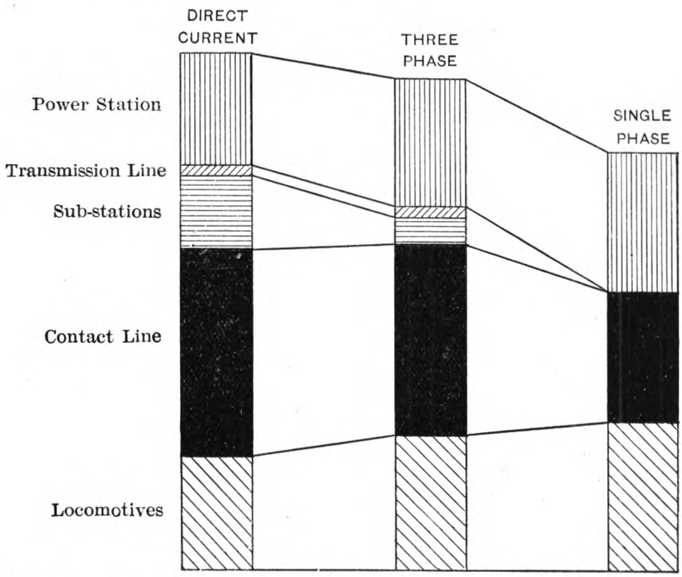


FIG. 39. COMPARATIVE FIRST COSTS IN THE DIFFERENT SYSTEMS FOR A SPECIAL CASE OF PUSHER SERVICE

322 The costs for power station include only the machinery and building and do not include cost of hydraulic development. It will be noted that the considerably less cost of the single-phase system in this case is due largely to the lower cost of contact line and sub-stations.

COMPARATIVE FIRST COSTS, SHOWN IN FIG. 39

323 Fig. 39 shows the comparative estimates of first cost for the three systems for pusher service on mountain grades in a particular case involving the use of twelve locomotives. The total length of line is 32 miles, part of which is single track, part double track and part three tracks. In addition to the main line there is a large yard to be electrified, there being a total of 90 miles of single track. The location of the power station was fixed by non-electrical considerations.

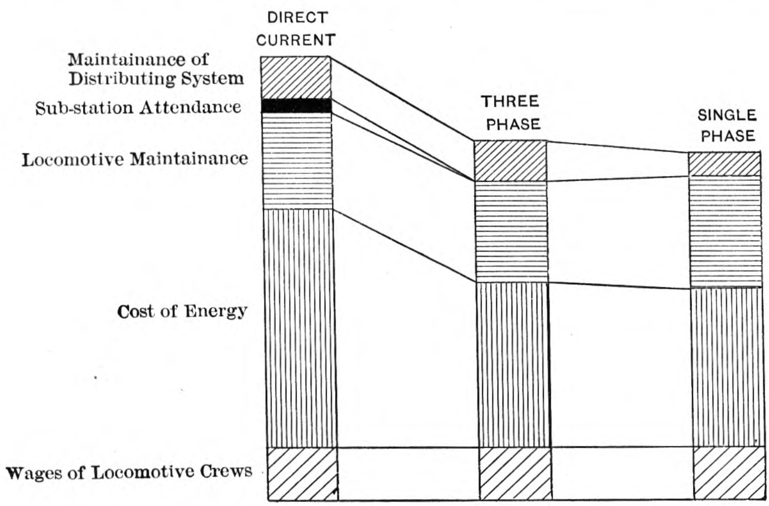


FIG. 40 COMPARATIVE OPERATING COSTS IN THE DIFFERENT SYSTEMS IN A SPECIAL CASE OF PUSHER SERVICE

The distances were such that sub-stations were required when either direct current or three-phase current was assumed, but the entire system could be fed direct from the generators if single-phase current was used.

324 It will be noted that in this case the omission of sub-stations and transmission effects a very considerable saving in favor of single-phase as well as the usual large saving in cost of contact line effected by the use of this system. The cost of the part of the system between the power house and the locomotives in the direct-current system is nearly equal to the cost of both power house and locomotives. On the other hand, the cost of the single-phase contact line, the only intervening element between the power house and the locomotives, is less than one-half of the cost of the direct-current transmission and contact system.

COMPARATIVE OPERATING COSTS, SHOWN IN FIG. 40

325 Fig. 40 shows comparative operating costs for the three systems for the pusher service outlined in the preceding diagram of first costs. It should be noted

that these costs do not include fixed charges. If fixed charges were included the difference in operating costs in favor of the single-phase system would be much more marked.

326 In connection with this diagram it should be noted that sub-station attendance is required for the direct current system only. The reason for the three-phase and single-phase systems being so nearly on a par is that this case is an ideal one for the application of the three-phase system since it involves constant-speed operation under constant-load conditions. It is notable, however, that even under these conditions the single-phase system shows somewhat lower operating costs than the three-phase system.

327 The high operating cost with the direct-current system is seen to be due largely to the greater amount of power required for operation by this system on account of the large losses which occur between the power house and the locomotive in this system.

APPENDIX No. 4

ELECTRIFIED STEAM ROADS AND ELECTRIC ROADS FOR TRUNK LINE SERVICE

328 The accompanying tables give data upon many of the important railroads on which electricity is used in heavy railway service. Only such data are included as were conveniently available and such omissions or inaccuracies as may occur do not detract materially from the forceful presentation of the extent and character of the use which is now being made of electricity in railway service.

329 The horsepower ratings of the various motor cars and locomotives are in general the nominal ratings for a short period, usually one hour, but as these ratings have been adapted in some cases to the particular service in which the motors are to operate they cannot be taken as a basis for an accurate comparison between the capacities of different equipments.

TABLE 26 SINGLE-PHASE ELECTRIFICATION
On Steam Railways and in Trunk Line Service

Road	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
N.Y.,N.H.& H. R.R.R. Main Line..........	21	100	11,000	4	600	41 2	1400 1600
New Canaan Br.....	8	8	11,000	2	500		
Grand Trunk R.R.....	3.5	12	3,300	...	...	6	900
Erie R.R. Rochester Div......	34	34	11,000	6	400	...	....
Colorado Southern Ry. Denver & Interurban	46	46	11,000	8	500	...	....
Baltimore & Annapolis Short Line.........	25	30	6,600	12	400	...	....
Swedish State Ry.....	7	7	3,300 20,000	2	240	1	300
Midland Ry., England	8.5	17	6,600	1 2	300 360	...	....
Prussian State Rys....	16.5	31	6,600	20 42 54	250 400 345	1	1500
London, Brighton & South Coast Ry.....	8.6	17.2	6,000	16	460	...	....
Rotterdam-Haag-Scheveningen.......	20.5	46.5	10,000	19	360	...	....
Spokane & Inland.....	129	129	6,600	28	400	6 5	500 720
Midi Ry. of France..	75	...	12,000	30	500	2	1600

TABLE 27 CONTINUOUS-CURRENT ELECTRIFICATION

ON STEAM RAILWAYS AND IN TRUNK LINE SERVICE

Road	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
N. Y. C. R.R.	33	132	650	137	400	47	2200
Pennsylvania R.R.	20	75	650	180	400	24	4000
West Shore R.R.	44	106	650	20	360	...	....
Long Island RR.	42	125	650	137	400	2	1200
West Jersey & Seashore R.R.	75	150	650	68	400	...	....
B. & O. R.R.	3.7	7.4	600	...	...	{ 2.5 5	1600 1100
Northeastern Railway.	37	...	600	...	300	2	600
Mersey Tunnel	4.8	...	600	24	400	...	....
Lancashire & Yorkshire Railway	18	60	600	...	600	...	....
Great Western Ry.	5	...	600	...	600	...	....
Metropolitan Railway.	...	67	600	56	600	10	800

TABLE 28 CAR EQUIPMENT OF SUBWAY AND ELEVATED SYSTEMS IN AMERICAN CITIES

THE DIRECT-CURRENT THIRD-RAIL SYSTEM AT APPROXIMATELY 600 VOLTS IS USED IN ALL CASES

Road	Miles of Single Track	Motor Cars	
		No.	h.p.
Boston Elevated Railway	19	219	320
Brooklyn Rapid Transit	71	{ 558 101	300 400
Interborough Rapid Transit (New York)	190	969 764	250 400
Hudson & Manhattan (New York)	12	140	320
Chicago & Oak Park	19.4	65	320
Metropolitan West Side (Chicago)	51.1	{ 15 210	400 320
Northwestern Elevated (Chicago)	25.5	{ 20 128	250 320
Southside Elevated (Chicago)	36.5	{ 150 70 150	180 150 110
Philadelphia Rapid Transit	11	100	250

TABLE 29 THREE-PHASE ELECTRIFICATION

ON STEAM RAILWAYS AND IN TRUNK LINE SERVICE

Road	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
Gt. Northern R.R. Cascade Tunnel.....	4	6	6600	..	..	4	1900
Italian State Railways.							
Valtellina Railway ..	66	...	3000	10	400	{ 2 { 7	800 1500
Giovi Railway......	12.4	37.3	3000	..	..	20	2000
Mt. Cenis Tunnel...	4.4	...	3000	..	..	10	2000
Savona Ceva.......	...	...	3000	..	..	10	2000
Swiss Federal Railways Simplon Tunnel....	13.7	14.3	3000	..	..	{ 2 { 2	1100 1300
Gergal Santa Fé (Spain)	13.1	14 4	5500	..	..	5	320

APPENDIX No. 5

THE EARLY HISTORY OF SINGLE-PHASE RAILWAY MOTORS

330 In Par. 230 brief mention was made of two single-phase motors of 10 h.p. built in 1892 by the Westinghouse company for determining the possibilities of using alternating current for traction work. These motors were designed for 2000 alternations per minute and about 200 volts. They were of the series type, with commutators, and had a relatively large number of poles. They were mounted

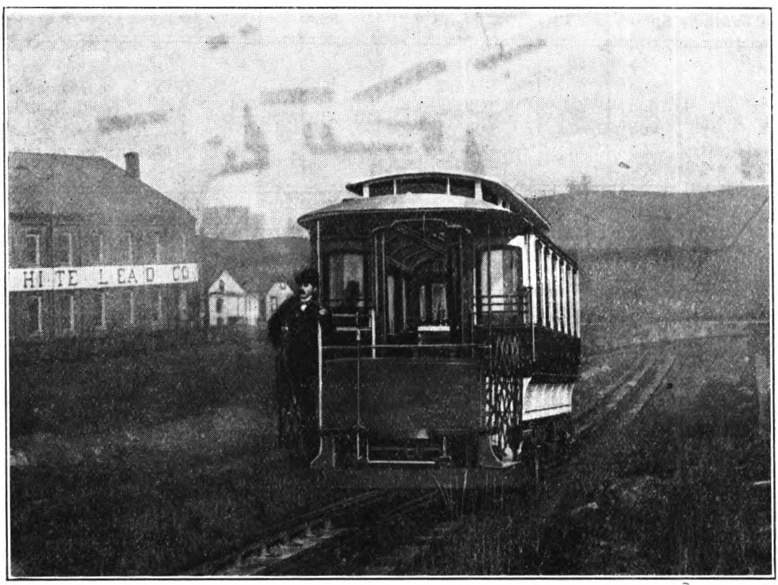


FIG. 41 THE FIRST SINGLE-PHASE ELECTRIC CAR. DESIGNED IN 1892 AND EQUIPPED WITH TWO SINGLE-PHASE SERIES MOTORS

upon a car and tested on a short piece of track with some very short curves and rather steep grades. The car is shown in the accompanying illustration, Fig. 41. The current was supplied from a conductor placed intermediate between the rails. The capacity of the engine and generator used for these tests was insufficient for the service, and the voltage drop in the rails was excessive. The test showed that the motors would run the car, although the current available was hardly sufficient for operating the car on the curves and grades. A transformer on the car served to transform from a few hundred volts on the supply circuit to that required for the motor. There were several taps on this transformer, and by means of several single-pole switches, the voltage could be varied. Several frequencies lower than that for which the motors were designed were employed for testing the motors.

331 Almost the entire effort in railway work at that time was concentrated on electric cars for city service. While the single-phase system gave promise of certain advantages for this service, it was found that there were disadvantages, particularly in the large losses in the conductors for supplying the current, which rendered the single-phase system much less adapted to this service than the direct-current system.

332 It was recognized that the single-phase system would be ideal for locomotive operation, but as no projects of this sort were then in view, no immediate work was done in building large motors of this type.

333 Some seven or eight years later, the enlarging field of railway operation was showing the imperative need of some practical method by which high tension could be used on the trolley wire in order to minimize the cost of supply circuits. Furthermore, the accrued experience and greater knowledge in the methods of designing alternating-current motors opened the opportunity for the development and perfection of the single-phase system.

334 Motors of 100 h.p. were designed, built and tested on an experimental track. The results of this work and the importance of the single-phase system in railway operation were presented in a paper by Mr. B. G. Lamme before the American Institute of Electrical Engineers in September 1902. This paper awakened widespread interest and was followed by the active development of single-phase apparatus by a number of manufacturing companies, both in America and in Europe. There are now about 60 single-phase railways in operation.