# Electrification of the Pennsylvania at Philadelphia

The electrification of the suburban service of the Pennsylvania between Broad Street station, Philadelphia, and Paoli is the first work of this nature undertaken by that company in the vicinity of Philadelphia. Its primary purpose is to increase the capacity of the Broad Street station and thus relieve congestion at that terminal. This station is of the stub-end type, having 16 station tracks approached by six main line and three yard tracks on an elevated railroad which crosses the Schuylkill river from West Philadelphia. At this point the routes divide toward the north for New York, toward the south to Washington and toward the west to Pittsburgh.

In addition to the through passenger service accommodated at Broad Street station, there is an extensive

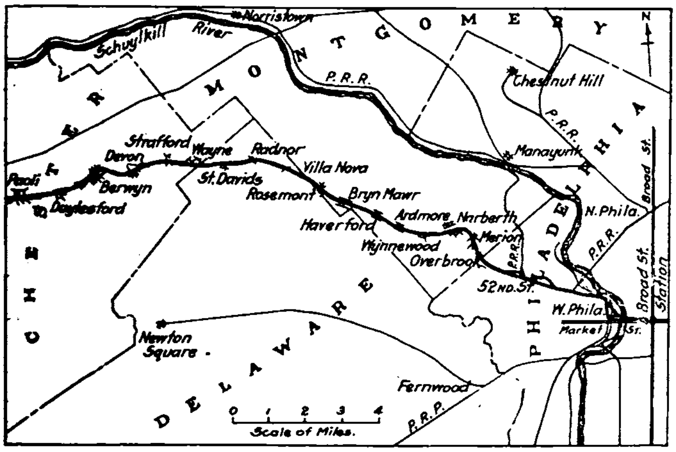


**Fig. 1. Map Showing Electrified Portion of the Pennsylvania Railroad Between Philadelphia and Paoli.**

suburban service extending over six different routes. The growth of all business in recent years has been such that the limit in capacity of the station has been reached and many plans have been formulated and discussed for relief by physical enlargement of the station and its approaches, or by rerouting movements. All of these plans involved extensive reconstruction and required much time for their accomplishment so that some more expeditious method of obtaining relief was desirable. The possibilities of electric traction as a means to this end were studied by committees of operating officials. Their analyses and estimates indicated that during rush hours the relief which would be secured by the electrification of the Paoli suburban service alone would increase the station capacity by an amount equivalent to reducing the total number of trains by about 8 per cent. A similar increase in capacity would result from the electrification of other suburban lines; work in connection with one of these, the Chestnut Hill Branch, has already commenced. This increase in capacity is effected by the elimination of the shifting back and forth from one track to another of cars, while the movement of light power is avoided. There is also some gain in capacity resulting from the quicker acceleration of trains and the shorter length of track occupied by a given train when the steam locomotive is not required. Relief thus afforded by the electrification of the Paoli and Chestnut Hill lines is estimated to be sufficient to take care of the normal growth of business for the next seven or eight years and the period of relief can be further extended by the electrification of other suburban lines, should the trial of this initial electric service meet expectations.

It is estimated that under electric operation there will be a sufficient saving in operating costs, as compared with steam, to pay interest on the investment, which in this case is exceptionally large for the reason that the entire Broad Street terminal, with its elaborate yard and approaches, form a part of the construction required for a relatively small amount of train service. This is not an unfavorable result under the circumstances, meaning as it does that the increased capacity thus obtained will in part, at least, be self-sustaining, whereas increased capacity by physical enlargement would give no direct return on the heavy investment. In addition there are the other contingent and important advantages of electrification such as the higher speed of trains, more punctual service, especially in bad weather, and more cleanly and attractive conditions for the traveling public.

### The Electric System.

A careful study of all phases of the problem, including service conditions, first and operating costs, available power supply, and the possible future electrification of the entire divisions affected, led to the conclusion that the most desirable system was one which used a high voltage, single, overhead contact wire and which eliminated rotating machinery in substations. It was, therefore, decided to supply 11,000-volt, single-phase, 25-cycle power directly to the cars from a single overhead catenary trolley.

While the studies which preceded this work involved the possible future electrification of several different railway divisions and classes of service, the present installation covers only the suburban service from Philadelphia westerly to Paoli on the main line of the Philadelphia division and involves about 43 trains each way per day. From Broad Street station the main tracks are electrified for 20 route miles, including a coach yard at West Philadelphia and a coach and repair yard at the end of the electrified section at Paoli. The present electrification embraces about 93 miles of single track.

### Power Supply.

Power for traction purposes is purchased from the Philadelphia Electric Company and is generated in its main power station at Christiansen street on the east bank of the Schuylkill river about a mile south of the West Philadelphia passenger station.

The power is delivered to the railroad company's Arsenal Bridge substation directly across the river, at 13,200 volts. There it is stepped up to 44,000 volts and by means of duplicate single phase overhead transmission circuits is transmitted to the step-down substations. While the present service is on one phase only of the power company's three phase generating system, the plan is to supply the succeeding or future electrification power requirements from the remaining phases. Special provision has been made by the power company to balance this single phase load and also to correct for the relatively low power factor in order that the full three phase capacity of the generating units may be available.

### Transmission.

Three-phase, 25-cycle power at 13,200 volts is transmitted from the Philadelphia Electric Company's generating station to the railroad company's Arsenal Bridge substation over four 350,000 C. M., 3-conductor armored submarine cables laid on the bed of the river. On the west bank of the river the submarine cables are connected to paper-insulated, lead-covered cables, which lead through clay ducts into the substation. Switchboard meters are provided on each of the incoming 13,200 volt feeders.

From the Arsenal Bridge substation to the West Philadelphia substation power at 44,000 volts is transmitted over four aerial single phase transmission lines.

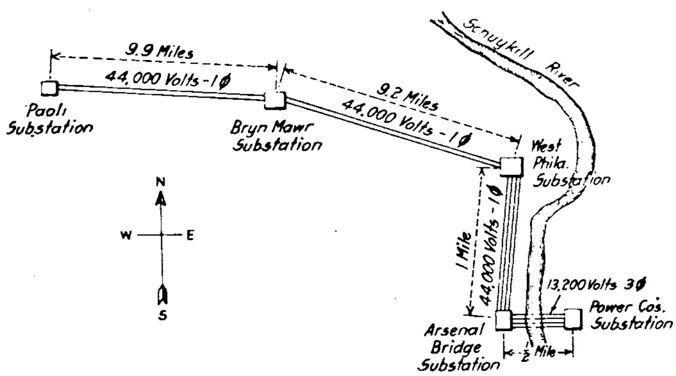


Fig. 2. Schematic Diagram of the Single-Phase, High-Tension Feeuers Beiween ıne Pniıauelphia Electric Company's Power Station and the Railroad Company's Substations. Each Line Represents a Two-Phase Feeder.

All four of these single phase lines tee into the West Philadelphia substation, two of them continuing on to the Bryn Mawr and Paoli substations. The other two will later go to the Chestnut Hill substation.

Between the Arsenal Bridge and West Philadelphia substations the four single phase transmission lines are carried on four two-pin steel cross arms attached to a structural steel pole which is supported by steel brackets from the side of the elevated structure. Beyond the West Philadelphia substation the lines are carried on the catenary supporting structures. Along the right-of-way the lines are carried on both sides of the track. Horn gap switches for sectionalizing are installed on the roofs of the West Philadelphia, Bryn Mawr and Paoli substations. Lighting arresters are installed on the roofs of all substations.

Each of the single phase transmission lines consists of two No. 00 seven strand, hard drawn copper wires. Wires of the same circuit are spaced 5 ft. apart on the cross arms. Where there are more than one circuit on a pole, the vertical spacing is 3 ft. 6 in. The lines are protected by a 3/8 in. stranded steel ground wire on the top of the poles.

Under the Belmont and Girard avenue bridge, which on account of its width approaches tunnel conditions, the lines are covered with rubber and varnished cam-

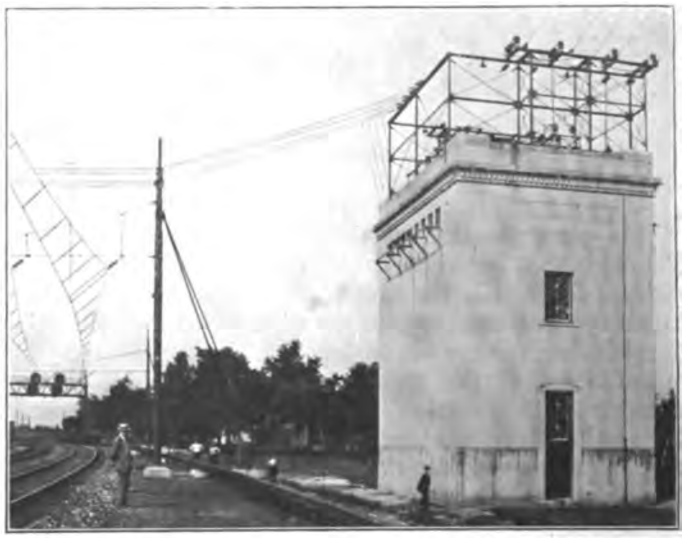

Fig. 3. Transformer Substation at Paoli, Pa., Showing Equipment on the Roof and Method of Bringing Out High-Tension Trolley Feeders.

bric insulation. At either side of the bridge the insulation is tapered off inside a porcelain sleeve filled with compound. The wire continues on through the sleeve and is jointed with the bare wire outside.

The pin type porcelain insulators used on the transmission lines are 8 7/16 in. high and 12 in. in diameter, and are made up of four parts. These insulators withstand the following tests:

| | |
|---|---|
| Dry flashover | 165,000 volts |
| Wet flashover | 120,000 volts |
| Puncture | 250,000 volts |

After erection, the transmission lines were tested out at a potential of 66,000 volts, or three times the working pressure, to ground.

At the Arsenal Bridge substation the lines are protected by time limit relays which operate on overload and on an unbalanced load in either leg caused by a ground. In the other substations the relays operate only differentially. In case of a ground be-

Fig. 4. View of the West Philadelphia Substation Showing Entrance of the Four Single-Phase 44,000-Volt Lines from the Arsenal Bridge Substation. The Method of Carrying These Lines on the Elevated Structure is Clearly Shown at the Extreme Right.

tween substations, the circuit on which the trouble occurs will be cut out first in three of the substations and finally at the Arsenal Bridge substation.

### Substations.

Transformer substations are provided for stepping up the voltage for transmission and for reducing it at suitable points along the railroad to that required for the contact conductors.

The substation equipment is housed in substantial fireproof brick buildings adjacent to the tracks. The lightning arrester equipment and high tension feeder sectionalizing switches are located on the roof, the bus bars and switching equipment on the second floor, and the transformers on the ground floor.

The installed capacity of the substations are as follows:

| | |
|---|---|
| Arsenal Bridge........ | 3—5,000 K.V.A. step-up transformers |
| West Philadelphia..... | 2—3,000 K.V.A. step-down transformers |
| Bryn Mawr........... | 2—2,000 K.V.A. step-down transformers |
| Paoli ................. | 2—2,000 K.V.A. step-down transformers |

Space is provided in all substations for 100 per cent. increase in capacity.

The transformers in all substations are of the 25 cycle, single phase, oil-insulated, water-cooled type. The primaries of the step-up transformers in the Arsenal Bridge substation are wound for 13,000 volts, the secondaries for 44,000 volts. The primaries of the step-down transformers in the other substations are wound for 44,000 volts, the secondaries for 11,000 volts. Several voltage taps are provided on the primary and secondary coils of all transformers. In each substation a transformer truck and chain hoist are provided for handling the transformers and cores. Each transformer case is also equipped with a thermostat which operates an alarm bell in case of high temperature in the transformer. Oil filtering and drying apparatus is located in each substation and a tank is provided into which the oil may be drawn from the transformers.

The neutral points of the high tension windings of the step-up transformers are grounded through a grid resistance. The potential to ground from either side of the 44,000 volt transmission lines is, therefore, limited to 22,000 volts.

Power at 110, 220 and 440 volts and 25 cycles for the operation of oil switches, for electric lights and for other miscellaneous purposes, is obtained from the high-tension buses through suitable step-down transformers.

In addition, an emergency supply of 60 cycle power is provided in all substations to trip circuit breakers in case of the loss of the 25-cycle traction power.

Except in the West Philadelphia substation where the power director or system operator is located, there are no attendants. A switchboard with the necessary instruments, controllers and indicating lamps, is provided in signal towers near the Arsenal Bridge, Bryn Mawr and Paoli substations. This board is connected with the board in the substation through a control cable, which arrangement permits the tower man to open and close all circuit breakers in the substation from his station in the tower. Telephones are provided in all substations and in the signal towers controlling them so that the power director is in constant touch with all substations and tower men. An alarm bell connected to the thermostat on the transformers is located in each signal tower.

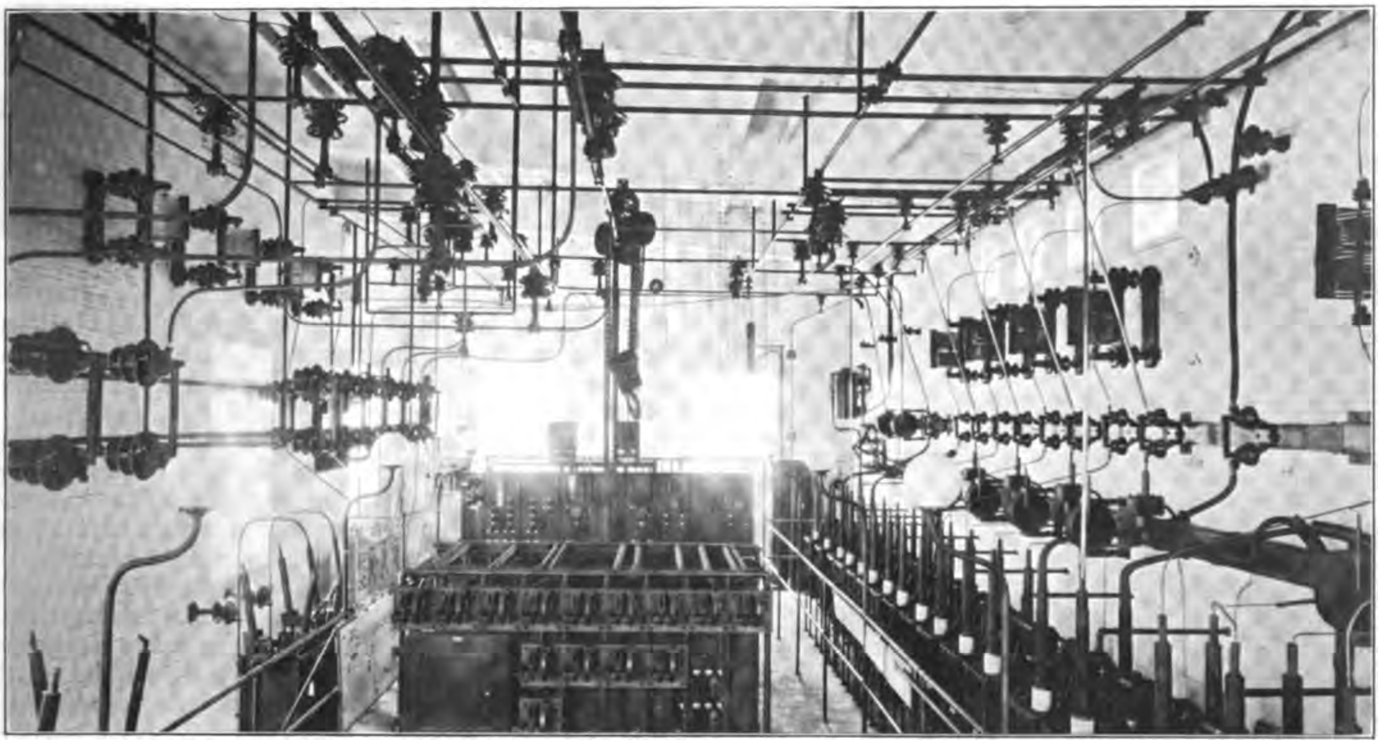

Fig. 5. Arrangement of Bus-Bars and Switching Equipment in a Typical Substation.

### Catenary System.

In order to try out the various types of structures and details considered for this work, an experimental four-track section about a mile long was completely equipped in the fall of 1913. An examination and study of this led to the adoption of what is called the "tubular cross-catenary bridge" for carrying the catenary trolley wires.

A photograph is shown of one of these structures before any longitudinal wires were erected. On either side of the tracks a tubular steel pole is set and grouted into a concrete foundation. Each pole has a double guy anchoring it away from the tracks. Spanning the tracks between the poles are the two cross wires forming the cross catenary bridge which carries the longitudinal messenger and trolley wires. This type of structure has been used throughout wherever the property or arrangement of tracks will permit. Where there is no room for guying, self-supporting structural steel posts have been used.

The tubular poles are built of various lengths, sizes and weights of steel pipe welded together. The guys are solid steel rods with heavy turnbuckles near the ground end to permit of adjustment. Numerous experiments and tests were made to determine the holding power and economy of various forms of guy anchors. The anchors finally adopted are of the deadweight type, each consisting of a concrete slab reinforced with old rails. Where the guy rods pass up

Fig. 6. Tubular Cross-Catenary Bridge Before Longitudinal Wires Were Erected.

through the soil they are protected against corrosion by means of a steel pipe, the space between the pipes and the rod being filled with grout. The guy rods are attached to the pole by heavy steel castings.

The cross wires are of extra high-tension galvanized steel strand, the upper strand usually being ¾ in. and the lower one ½ in. in diameter. Both are socketed at each end, and at one side a turnbuckle is installed to permit adjustment. The top and bottom cross wires are joined together by a ¾ in. vertical rod and suitable malleable iron clamps, etc., at the points where the insulators carrying the longitudinal wires are located.

Each of the insulators that are supported by the cross catenary wires consists of three suspension type units, the porcelain being 8 in. in diameter. The flashover value of the complete insulator is many times that of the line voltage. The cross wire bridges are located about 300 ft. apart on tangents, but are closer on curves. After the bridges were erected, insulators were suspended over the center of the track on tangents and offset towards the outside of the track on curves. The main messenger wire was then strung out and suspended from them. This is a ½-in. extra high tension 7-strand double-galvanized steel cable, having a sag of 5 ft. in a span of 300 ft. Every mile or two this messenger is socketed and dead-ended on one of the heavy structural signal bridges which are placed about ½ mile apart. Where so dead-ended the

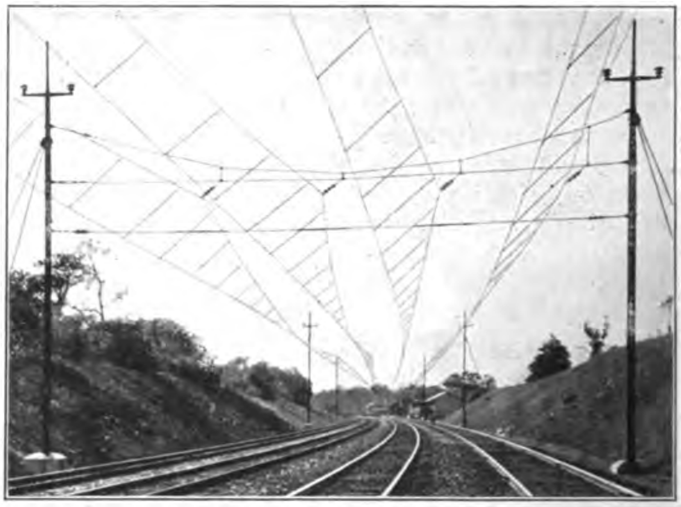

Fig. 7. Catenary System Over Curved Track.

messenger is insulated from the signal bridge by two or more sets of the three unit suspension type insulators used for suspending the messenger from the cross wires on other bridges.

An auxiliary messenger wire and the contact or trolley wire are suspended from the main longitudinal messenger wire by suitable hangers. The hangers are placed 30 ft. apart over tangent track and 15 ft. apart over curved track. On tangents, the casting at the bottom of the hangers holds the auxiliary messenger only; the trolley wire is then supported from this auxiliary messenger every 15 ft. at points midway between the hangers. This insures a flexible and smooth riding trolley wire. On curves the casting at the bottom of the hangers holds both the auxiliary messenger

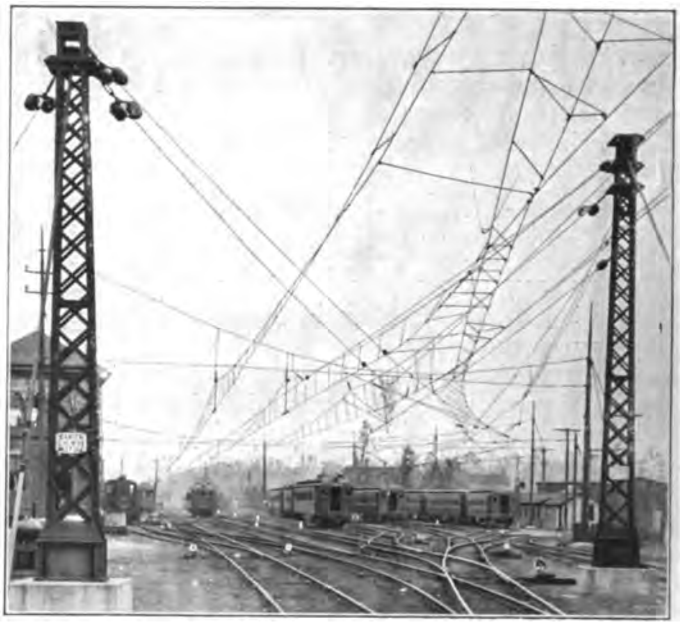

Fig. 8. Catenary Construction at the Paoli Yard.

and trolley wire. Except at overhead highway bridges the trolley wires are carried about 22 ft. above the top of the rail.

In the Terminal division, which includes the first five miles from Broad Street station, where the steam locomotive traffic is very dense, and where there is much smoke and corrosive gas, a non-corrodible tube hanger is used. Some of the tube is Monel metal,

Fig. 9. Wrought Iron Trolley Hanger and Method of Its Attachment to the Wires in Curved Track Construction.

while the balance is a bronze mixture containing 90 per cent. copper. On the Philadelphia division, where there is relatively less steam traffic, wrought iron strap hangers, 1 in. wide by 3/16 in. thick, are used. The main messenger cable at the hanger clip is protected from corrosion by a collar of zinc inside of the annealed brass or Monel metal clip, which is bolted to the hanger strap. The flat hangers were given a quarter turn so as to have the widest dimension in a vertical plane, the idea being to minimize the area exposed to the wind in a direction crosswise with the tracks, and also to better resist bending when placed on curves.

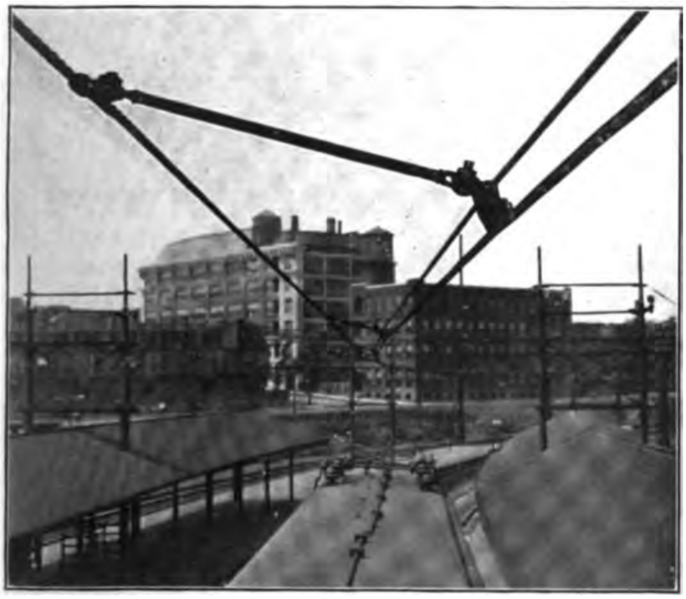

Fig. 10. Non-Corrodible Tube Trolley Hanger.

The auxiliary messenger wire is of No. 0 round B. & S. solid copper, and its purpose is to give the necessary current capacity to the system. The contact wire is a No. 000 grooved B. & S. "Phono-electric" trolley wire.

The tensions in both the auxiliary messenger and trolley wires are selected so that in extreme hot weather there will be enough tension to prevent sagging and yet in extreme cold weather the contraction will not cause stresses beyond the elastic limit.

The catenary system over each of the four main tracks is separated electrically from those over the other tracks, and trolley sectionalizing points with switches are provided at all crossovers so that sections of the line may be temporarily cut out of service for repairs.

On the main running track sectionalizing is of the "air-brake" type, the trolley wire of one section passing the trolley wire of the other section at the same level so that the pantagraph may come in contact with both. The ends of both trolley sections are then raised, insulated and dead-ended.

At crossovers and in yards the trolley wires are sectionalized by means of wood stick insulators, having runners on each side so arranged that while the pantagraph always makes contact with at least one of them they are separated electrically. Switches of the disconnecting knife blade type are mounted on top of the wood insulators. They are operated from the ground by a long impregnated wooden switch stick.

Fig. 11. Special Car for Erecting Catenary Work; Removable Outriggers Make It Possible to Work Over Adjacent Track Without Interruption to Traffic.

The electrified route is crossed in many places by overhead highway bridges, some of which are not high enough above the tracks to permit the trolleys being carried at the normal height of 22 ft. In such cases if it was impracticable to raise the highway bridge the trolley wires gradually dip and go under the bridges at a height less than 22 ft.

The catenary bridges are so located that these highway bridges come in the center of a span where the vertical height necessary to clear the catenary system is a minimum. Each catenary system, as it passes under a highway bridge, is steadied by being held with post type insulators mounted on brackets fastened to the bridge structure.

To prevent pedestrians on the bridges from touching or interfering with the wires solid wooden fences, either vertical or inclined, and of sufficient height to shut out all view of the wires, have been erected. In order fully to protect the trainmen, general orders have been issued that no men are allowed on top of any car in the electrified zone.

An interesting detail in the erection of this catenary work was the use of special construction cars, the top platforms of which could be readily raised or lowered by chain hoists. These cars were also equipped with removable outriggers so that in the four-track section the work could be completely erected over a track adjacent to the one on which the car was standing without interfering with the regular steam traffic on that track.

### Bonding.

In order to furnish a circuit for the return of the traction current to the substations, each rail joint of the main line tracks is double bonded with two pin type, expanded terminal, No. 0 B. & S. bonds. One end of each bond has a welded terminal, while the other end has a soldered terminal. With this arrangement it is possible to install the bond by slipping it behind the splice plate. Through the interlockings only one rail of each track is bonded. The bonded rails of the various tracks are, however, connected together.

The track rails are sectionalized at each signal block by insulating joints, across which are placed impedance bonds. These impedance bonds allow the passage of the traction current, but sectionalize the track so far as the 60-cycle signal current is concerned.

### Booster Transformers.

To minimize the inductive effect of the traction current on adjacent telephone and telegraph wires, a special system has been installed. This consists of series or booster transformers located about a mile apart. These transformers are mounted on the signal bridges and the current in each of the trolleys is constrained to pass through a primary coil of the transformer, thus inducing an equal current in the secondary coil, the ratio of the transformers being approximately unity. The secondary coils of these transformers are connected across insulated joints in the track. Consequently as all trolley current must flow through the primary coil the secondary coil insures that all the returning traction current, at this particular point of the circuit at least, must pass through the rails. In this manner the traction current is prevented from taking earth returns in parallel with the track or if there is a tendency between these booster transformers for the traction current to seek an earth return this tendency is corrected at the next booster transformer which constrains or picks up all the traction current and again starts it through the rail. A typical signal bridge with these booster transformers is shown in Fig. 17. By thus confining the return traction current in or near the rails and therefore keeping it as near the trolley as possible, its inductive effect on adjacent telephone and telegraph lines is practically eliminated. This is of course in complete harmony with the laws governing mutual inductance which are to the effect that the closer two wires of the same circuit are to each other the less their self-inductance and therefore the less their mutual inductance on a near-by parallel circuit.

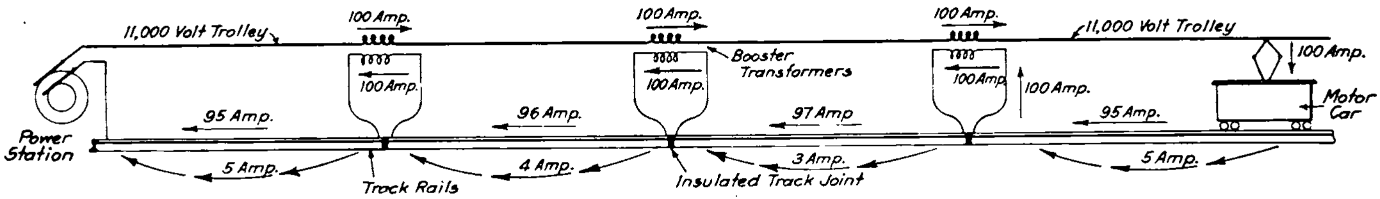


**Fig. 12. Elevation Diagram Showing Booster Transformer Connections. The Arrows at the Bottom Indicate the Action of the Transformers in Gathering Up the Ground Currents at Each Transformer Location.**

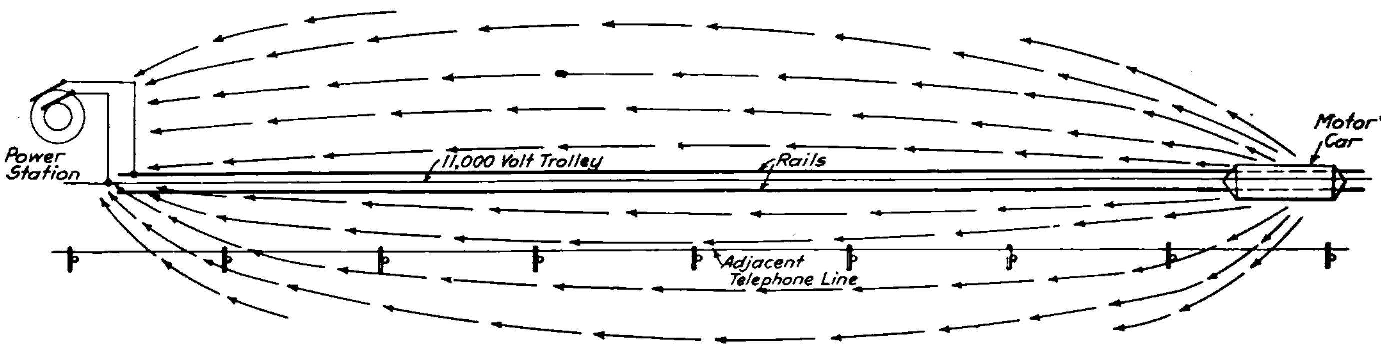


**Fig. 13. Plan View Showing Large Amount of Ground Currents Flowing Between Motor Car and Power Station When Booster Transformers or Some Other Corrective System is not Employed.**

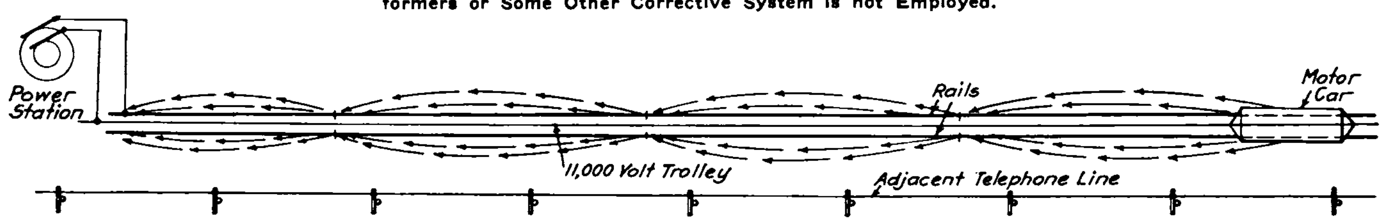


**Fig. 14. The Use of Booster Transformers Confines the Greater Part of the Return Traction Current in the Rail and Thereby Eliminates Objectionable Inductive Effects on Adjacent Telephone and Telegraph Lines.**

Diagrammatic sketches showing how the use of booster transformers confines the return traction current to the rail, thereby eliminating its inductive effects on parallel telephone and telegraph lines, are shown in Figs. 12, 13 and 14. The transformer connections and the current distribution are shown in Fig. 12. It is, of course, understood that the sketch shows a rather ideal condition. In actual practice small, negligible ground currents will no doubt flow on past the insulation joints, in which case the booster transformer will cause an equal current to flow in the reverse direction around the insulation joint through the ground so as to bring the value of the secondary current up to that of the primary or trolley current. The wide spreading of the return traction current that would be expected in case no booster transformers were employed is illustrated in Fig. 13. Fig. 14 shows that, by using the booster transformers the amount of current seeking a ground return is reduced to a minimum.

Fig. 15. Multiple Unit Train on the Electrified Portion of the Pennsylvania Between Philadelphia and Paoli. Each Car Is a Motor Car, No Trailers Being Used.

### Car Equipment.

One of the interesting features of the electrification was that the standard suburban steel coaches of the type used in the regular steam service have been used for the electric service without structural changes. This was made possible by the fact that the requirements for mounting electrical apparatus on the cars had been thoroughly considered at the time when the steel car was introduced on the railroad. A typical multiple unit train is shown in Fig. 15.

The rolling stock equipped for electric service consists of 93 standard all-steel cars. Tighty-two are passenger, nine combined passenger and baggage, and two combined baggage and mail. All cars are motor cars designed for double end operation. No trailers will be used.

The main circuit connections are shown schematically in Fig. 16. Current is collected from the overhead wire by a pantagraph trolley and is conducted to the main transformer through the line switch which is an oil circuit breaker. Various voltage taps are made on the secondary of the transformer and connections are made to these various taps in the proper sequence by means of unit switches. This sequence is also indicated by Fig. 16.

The motors, which are connected in series, are started and operated up to approximately 15 m.p.h. as repulsion motors, with the auxiliary or compensating field, the armature, and the main field in series. With these series connections, the armature is short-circuited through resistance. Resistance is also inserted in series with the motors on the first step and is cut out on the second step. The third step changes the connections to energize the auxiliary field from one portion of the transformer and the armature and main field, connected in series, form another portion of the transformer, thus affording doubly fed connections. The armature short-circuit is removed when operating as doubly fed motors. Subsequent steps are obtained by increasing the voltage across the auxiliary field and across the motors.

Each motor has an hourly rating of 225 h.p. and a continuous rating of 200 h.p. with 300 volts across the armature circuit when ventilated with 1,200 cubic feet of air per minute, and is provided with a 24-tooth pinion which meshes with a 55-tooth flexible gear. The armature is of standard construction, the commutator and the laminations being mounted on the spider, the former being undercut 1/16 in. The armature is wave-wound, cross-connected and no resistance leads are used between the windings and the commutator. The field windings consist of two entirely independent sets of coils; one, the main field circuit for producing the effective magnetic field; and the other an auxiliary or compensating winding which balances the armature reaction on the field and, in addition, has a neutralizing effect on the sparking voltage. The field consists of six poles, the coils being of copper bars suitably insulated, connected at the ends by straps.

The flexible gear, as shown by Fig. 18, is made up of a rim, on which the teeth are cut, a center, a cover plate and spring details. The rim is spring mounted on the center, the periphery of the center and the cover plate acting as the bearing surfaces for the rim.

The pantagraph is of especially light construction. The springs which raise it are designed to give flexibility to the framework, so that in operation a slight dragging of the trolley takes place, resulting in its following the wire much closer than with a rigid framework. In addition, the shoe is spring mounted on the framework. The trolley is provided with four insulators suitable for 11,000 volt service, and the whole mechanism is mounted on a base provided with insulators similar to those of the trolley, thus providing double insulation. The trolley is lowered and unlocked by air at 70 lb. pressure. A small hand pump is provided for unlocking the trolley when no air pressure is available.

The transformer is of the two-circuit air-blast type and is suspended from the center sill of the car as close to the motor truck as possible. The high tension leads are brought in the end of the transformer nearest the motor truck and the low tension leads are taken from the opposite end of the transformer. Ventilating air is taken in at the low tension end and is discharged at the high tension end through especially constructed hoods which cover the air outlets to prevent the entrance of rain and wheel wash. The coils are mounted vertically and are bakelized, thus giving an insulation which will withstand high temperature without damage.

Nine electro-pneumatic operated switches of standard construction are mounted in one group. The right hand end plate of this group is provided with covers and forms the base for the reverser. The current limit and the control terminal board are also mounted on this end plate, at the right-hand side of the reverser. The reverser drum is built of bakelized micarta tubing on which are mounted the contact plates, and is electro-pneumatically operated.

The limit switch is of novel construction. The current coil which is connected in the auxiliary field circuit of the motor surrounds a plunger which carries the control contact disc. The two settings of the limit switch are obtained by changing the weight of this

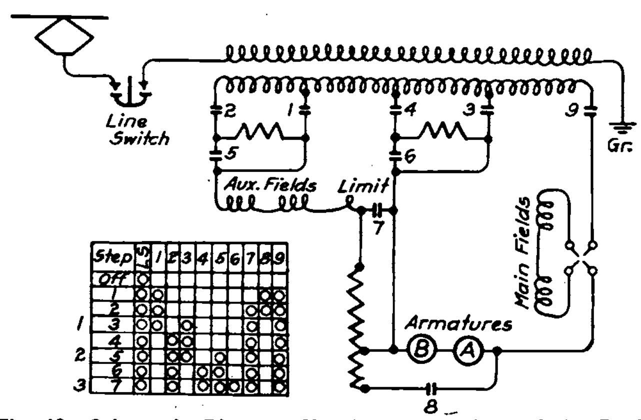


Fig. 16. Schematic Diagram Showing Connections of the Doubly Fed Motors.

plunger. This is done by lifting a weight from the plunger by means of a battery coil mounted above the current coil.

The master controllers are of the single handle type. Two plug receptacles are embodied in this controller and a single plug is attached to the handle by a chain. Placing the plug in the "cutout" receptacle completes the circuit energizing the line switch valve magnet and also connects the controller drum to the battery positive wire. Placing the plug in the "reset" receptacle connects the reset-wire to the battery positive train line wire. Nine controller positions are provided; an emergency or "dead man's" position in the center, and an "off," first, second and third running positions, for both forward and reverse movements. The controller drum is spring returned, and if released, will return to the middle or emergency position. In this position, the control is cut off and a valve magnet is energized which releases air from and operates a brake pipe relay, thus applying the emergency brake. This emergency circuit is local for each car. Each controller also has two push button switches for unlocking or lowering the trolley. To unlock the trolley, the control plug must be in the "cutout" receptacle, but the trolley may be lowered without the plug being in place. Each controller is mounted at the right-hand side of the vestibule, together with the motorman's brake valve, the signal whistle and magnet, and the cab heating equipment. This is shown by Fig. 19. When not being used, the end vestibule door is swung back to cover all this apparatus.

Control energy is obtained from a motor generator set operating in parallel with a battery. The motor is of the single-phase induction type with a starting winding that is cut out of circuit when the motor has attained speed.

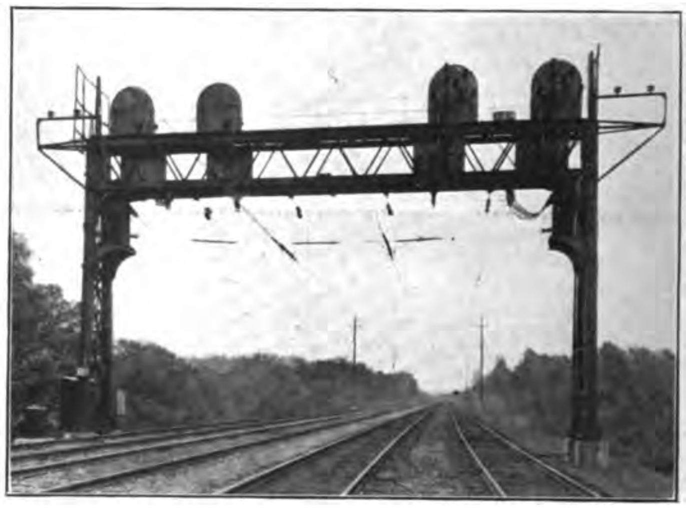

Fig. 17. Signal Bridge, Showing Anchor Insulators in the Main Catenary Messengers. A Booster Transformer is Shown Near the Top of Each Leg of the Bridge.

Ten control wires, including the battery plugs and ground wires, are required between cars for control operation. Nine of these are carried between the cars through a nine-point receptacle and jumper and the tenth is carried on the seven-point train line required for the electric brake circuits described later. The two nine-point control receptacles are mounted on each end of the car, one on each side of the coupler, and are connected in multiple.

A line or voltage relay is provided for cutting the d.c. control generator from battery, and also to operate two small emergency lights, and headlights in case the traction power should fail. This relay, together with the lighting fuses, control governor and heater switches and compressor motor switch, is mounted on a panel placed in the vestibule cabinet at the motor end of the car. This switchboard is of slate and all apparatus mounted on it is front-connected, thus facilitating inspection.

The fan for ventilating the transformer and motors is a 21 in. single inlet Sirocco wheel, and is mounted on the shaft of the motor which drives the compressor. The motor drives the fan continuously and the pinion driving the compressor is connected to the motor by a disc clutch. This clutch is normally held closed by a spring and the governor operates a magnet valve which opens the clutch by air pressure. The motor is of the doubly fed type and operates at approximately 980 r.p.m. at normal voltage with the combined loads of the fan and compressor, while the speed with the fan alone is approximately 1,300 r.p.m.

The air brake equipment of each car consists of two main reservoirs with radiating pipes, one safety valve on the main reservoirs, one compressor governor, two motormen's brake valves, with feed valves and reduction limiting valves, two combined equalizing and reduction limiting reservoirs, one emergency or quick recharge reservoir, one auxiliary and one service reservoir, one universal valve, one main reservoir bypass and limiting valve, one double check valve, one brake cylinder, one automatic slack adjuster, two duplex air gages, four seven-point train line receptacles, one seven-point train line jumper, one brake pipe, one main

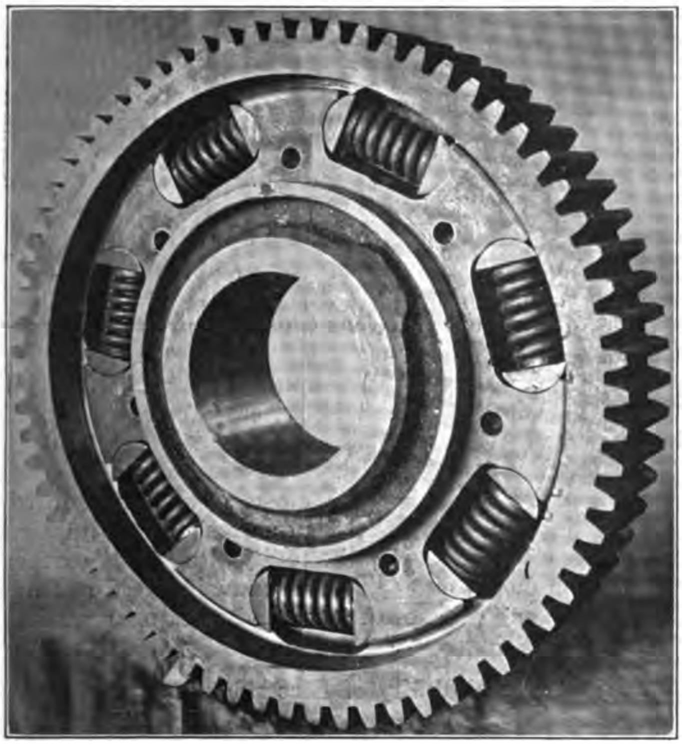

Fig. 18. Flexible Gear with Cover Plate Removed.

reservoir pipe, and one set of accessories, which includes cutout cocks, air strainers, hose, dirt collectors, switches, etc. This equipment is designed so that it may be used either in steam or electric service, and differs from the ordinary pneumatic brake in that the brake pipe reduction is made on each car by means of electric control instead of being made entirely with the engineer's brake valve. The addition of electric control to the pneumatic brake does not change its function in any way, but shortens the time required to get the brakes applied on all cars.

The motorman's brake valve contains both electric contacts and pneumatic parts, the electric portions being mounted above the pneumatic portions. There are six positions: (1) the release and running, (2), the electric holding, (3) the handle off, (4) lap, (5) service, and (6) emergency. The first named position is to the left and in this position all train brakes are released and the system charged. The "electric holding" position, as the name implies, holds the train brakes through electric control system but recharges the system. Pneumatically, this position is identical with the release and running position. All ports are closed in the "handle off" position, and the handle may be removed; in the "lap" position, the ports are also closed. The "service" and "emergency" positions are for applying the brakes for service or emergency application. In making a service application, a limiting valve in conjunction with the brake valve allows a maximum reduction of 20 lb. in the brake pipe. A small cutout plug is provided for cutting out the electric operation when desirable. The main reservoir pressure carried is 100 lb. and the brake pipe pressure is 70 lb.

Eight wires, including the battery plugs and ground wires, are required for the electric control of the brakes, for governor synchronizing and for train signaling. Since the two battery wires are common to the brake control and the unit switch control, a seven-point receptacle and jumper is used to carry the brake control wires. Two receptacles are mounted on each end of the car and on each side of the coupler and are connected in multiple in the same way as the nine-point receptacles for the unit switch control.

Trains of from two to seven cars are operated in regular service, the average acceleration on a straight level track being approximately one m.p.h.p.s. up to 30 m.p.h. with a balancing speed of 60 m.p.h.

**Engineering and Construction.**

The design and construction of the electric installation was carried out by Gibbs & Hill, consulting elec-

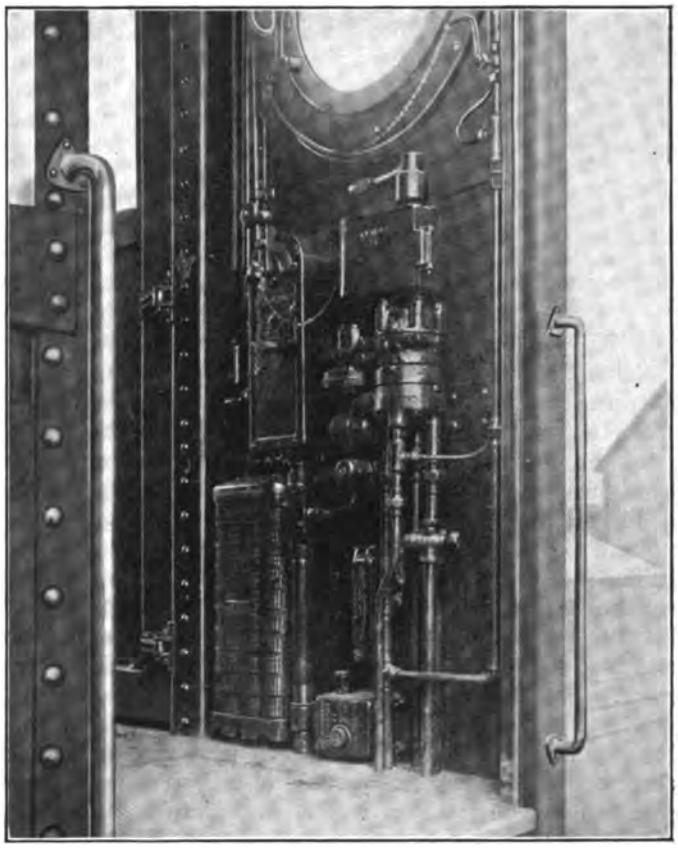

Fig. 19. Motorman's Position in Right Hand Side of Vestibule.

trical engineers for the company, in co-operation with the engineering department and the officials of the road. All construction except that of substation buildings and inspection building, which were covered by outside contracts, was carried out by a specially organized force.

The mounting of the multiple unit car equipment on the cars was carried out by the railroad forces at the Altoona shops under the direction of the motive power department. The signal equipment and changes in telegraph and telephone lines were designed and installed under the direction of the signal and telegraph departments respectively of the railroad company.