The question of a proper electric system was given especially careful study because of the difficult physical conditions and the unprecedentedly heavy haulage requirements. It was apparent that an electrified third rail along the tracks was not practicable under the local conditions and that some system using an overhead collector would be required. This narrowed down the problem to a decision between the high-tension direct current and the high-tension alternating current systems. Analysis of both first costs and operating cost, as well as consideration of the local operating conditions, indicated that the single-phase alternating current system was the one that should be adopted.

Attention might be called here to the fact that these heavy trains require enormous power for their movement, which in turn means large currents to be collected if the potential is low, but is effected with much smaller currents if a system with the maximum allowable potential is used. The practical difficulties of collecting large currents from an overhead wire are well known, and the adoption, therefore, of a high trolley voltage was a logical solution of this problem. Electric braking down heavy grades, accomplished in a simple manner, was another attractive operating feature of the system adopted.

In working out the details of the installation a number of novel features were introduced, notably in the adoption of three-phase motors on the locomotives in connection with single-phase current delivered to the locomotives. The required three-phase current for the motors is produced by a "phase-converter," which is a simple self-contained piece of apparatus. The three-phase motor used for driving the locomotive is an unusually rugged piece of electrical machinery requiring no commutator and having high weight efficiency, or capacity for given weight and dimensions. It has, however, a constant speed characteristic which is not desirable in some kinds of railroad operation, but for this particular service has important advantages in respect to maintaining certain predetermined and limited train speeds irrespective of the loads. Furthermore, this type of motor has the valuable characteristic of automatically returning regenerated current to the line on the down grades, this being effected without additional machinery or complication when the predetermined running speed is slightly exceeded during the coasting period. This characteristic may, at times, result in a considerable saving of power as the regenerated current is available for use in assisting to propel other trains which are in movement on the division, but its most valuable feature is that of "dynamic braking," or the holding of the train at a uniform speed on down grades without the use of air brakes.

Twelve electric locomotives have been provided for the service, replacing 34 Mallet steam locomotives. Each electric locomotive consists of two units weighing 135 tons, giving a total weight of 270 tons for the complete locomotive. The frame of each unit consists of two trucks connected by a Mallet type hinge, and each truck has two driving axles included in the rigid wheel base with a radial two-wheel leading truck. The bumping and pulling stresses are transmitted through the main trucks frame and through twin draft rigging mounted on the main trucks at each end of the unit. The main trucks each carry two motors framed into the truck and both meshing into the same gear on each end of a jackshaft. The main gears are provided with crank pins from which connection to the driving-wheel cranks is made by side rods in the usual manner. By this arrangement the motors are carried on the main locomotive springs and are thus thoroughly cushioned against shock. Each half of the locomotive is provided with a cab supported on the trucks entirely by spring cushioned friction plates. The center pins carry no weight and serve only to maintain the cab in its proper position on the trucks. The cabs contain all current controlling and transforming apparatus, air-brake pumps, reservoirs, and the usual appurtenances for the locomotive operation. There are two running speeds for the locomotive, namely, 14 miles per hour and 28 miles per hour.

The drawbar pull of the locomotive varies from a maximum of 114,000 lb. during acceleration to the 14-mile speed to 86,000 lb. when operating at this speed uniformly on a 1 per cent grade, but on test the locomotive has developed a tractive effort in excess of 170,000 lb. This indicated, however, a coefficient of adhesion which cannot be assumed in practice. The maximum guaranteed accelerating tractive effort per locomotive is 125,000 lb.

A valuable characteristic of this type of electric locomotive is its capability of safely exerting full tractive effort for a considerable time while standing. The utility of this will be seen when it is remembered that the trains hauled are generally over one-half mile in length, or three-quarters of a mile in the case of an empty train. When starting there is sometimes difficulty in getting coincident action between the head and rear locomotives, and thus it is specially important that both locomotives may be able to exert their full tractive effort for an appreciable time to take care of delays in getting into full action. Consequently, the motors have been designed to permit full load current to be applied for five minutes without movement.

Electric operation has been in service too short a time to give data as to performance, but it may be said that the estimates of increased capacity to be obtained from this equipment have been fully met and that an unusually heavy tonnage has already been handled without congestion, and the gathering and delivery tracks kept clear. The movement of the heavy tonnage trains by electricity has been effected with ease and smoothness; the trains accelerate promptly and without shock or jerk on the heavy grades, and it has been found that the full trains can be smoothly controlled by one head engine on the 2.5 per cent down grade by electric braking alone and at a uniform speed slightly above that of the regular running speed. The acceleration of one of these heavy trains is impressive as regards the amount of power required. Preliminary tests indicate that getting a train in motion up the grade requires as much as 11,000 electrical horse-power and that running at uniform speed up the grade requires 8,000 electrical h-p. to be delivered to the train. It is believed that no such amount of power has ever before been developed on a single train, either steam or electric, in regular service.

Electrification on the Chicago, Milwaukee & St. Paul

The Chicago, Milwaukee & St. Paul were first interested in electrification at the time their extension from the Missouri River to the Pacific Coast was under construction.

The section under consideration was through the Bitter Root Mountains, and the reason for its consideration was to lessen the fire hazard, as the line was building through a very extensive and important forest reserve of the United States Government.

The power was to be developed from a number of sites on the St. Joe River. The plans for this electrification were developed by consulting engineers who had decided upon a single phase trolley. The plan was abandoned owing to the insufficiency of the power available on the St. Joe River. In the meantime the road secured a site for power development on Clark's Fork of the Columbia River at Thompson's Falls, in Idaho.

The time which had elapsed did not permit of this development to provide for the initial operation of the road so that the Pacific Coast extension was placed in operation with steam locomotives using oil for fuel through the forest reserve.

The Chicago, Milwaukee & St. Paul in their operations to secure terminal facilities at Butte and to secure traffic for their new road, established relations with the Amalgamated Copper interest in Montana and acquired a substantial interest in the Butte, Anaconda & Pacific Railroad, which was owned by the Amalgamated Company. About this time the Great Falls Power Company, which was also controlled by the copper interests, was seeking a market for power from their important development, and to that end acquired the Madison River Power Company and the Butte Electric Company, which were controlled by Mr. C. A. Coffin, President of the General Electric Company, and affiliated interests, the combination being called the Montana Power Company.

About this time a representative of the General Electric Company made a report on the electrification of the Rocky Mountain Division of the Chicago, Milwaukee & St. Paul, based upon duplication of the locomotives and substation apparatus in use on the Butte, Anaconda & Pacific. The traffic was assumed to be five 1600-ton freight trains each day in each direction, two through passenger trains and one local passenger train each direction over a section of the line daily, the service to accommodate this traffic was laid out upon a train sheet and the use of power represented to be maximum of 10,000 kw. with an average of 6500, no consideration of regeneration or control of peak having been contemplated.

Based upon this report the contract was made with the Montana Power Company for a nominated sum of 10,000 kw. for the Rocky Mountain Division with options provided under certain terms for an increase to a maximum of 25,000 kw. The contract further provided that apparatus would be secured by the railroad capable of regulation of power factor, and that a minimum monthly charge would be equivalent to an average of 60 per cent of the nominated maximum power.

The railroad entered into a similar contract for the extension of the electrification to include the Missoula Division from Deer Lodge, Mont. to Avery, Ida., this involving as well the transfer of the Thompson's Falls Power site to the Montana Power Company's interests. About this time it was found that the original basis for the company's load diagram was fictitious, that the traffic was not balanced east and westbound, but fluctuated widely, due to seasonal and local variations. It was also concluded that 1600 ton trains in trans-continental service were entirely too small for the efficient movement of traffic. This led to the determination that the minimum trains should be 2500 tons hauled by a single locomotive on a one per cent grade. A third conclusion was that the topography of the road was particularly suited to regeneration and that this would be required. A fourth conclusion, which was insisted upon, was that automatic means should be provided for the limitation of the maximum demand for power.

The Westinghouse Company submiteed an analysis including an estimate on the cost of electrification, based on a single phase trolley, split phase locomotives for freight service, series commutator motors for passenger service and sub-station apparatus, to convert from 60 cycles to automatically reduce both voltage and frequency when the demand exceeded the predetermined peak setting. Each locomotive and each dispatcher's office to be equipped with frequency meters so that at all times those interested in the condition of power demand would be able to function advisedly.

At this time the question arose as to the engagement of an independent consulting engineer, but at a subsequent meeting of the Board of Directors of the Railroad Company, it was voted that the road would not employ an independent engineer and formal action was taken that the electrification would be affected by high voltage, direct current, the same as the Butte, Anaconda & Pacific, the position having been reached without engineering analysis and no further consideration has been given to the question of choice of system.

The entire undertaking was committed to a vice-president in charge of electrification, who employed as his assistant an electrical engineer to work out the technical detail. The analysis of the probable load conditions with 2500-ton trains led to the conclusion that a voltage higher than 2400 was economical and desirable and should be available.

Supporting this position was a demonstration by the Westinghouse Company of a high voltage car equipment which was operated at 6000 volts, direct current, and this led to the insistance that 3000 volts would be the nominal operating voltage to which the General Electric Company finally agreed.

The contracts finally made with the General Electric Company covered the present electrified section of 440 miles from Harlowton, Mont. to Avery, Ida. The technical requirements as to detail of sub-stations, transmission line, trolley construction, and locomotives were most precise and the response of the General Electric Company to the exacting specifications was complete, so that the execution of this electrification has been unique in the perfection of its detail.

The maintenance of the electrical equipment has been handled with equal skill. However, it is granted that the conditions local to this section of the country contribute toward this result, so that overloading, abuse or neglect in the operation of this equipment may be considered to have been entirely absent throughout its whole history.

The technical result of the electrification has been quite a success. The financial result, due particularly to fuel and labor conditions, and the indirect value due to the publicity of this operation, are equally as satisfactory.

In addition to the electrification of the Rocky Mountain and Missoula Divisions, the railroad began, in March, 1917, the electrification of an additional 207 miles of main line on the Columbia and Coast Divisions extending from Othello to Tacoma, Washington, and to Black River, nine and one-half miles south of Seattle, across the Saddle Mountains just west of the Columbia River and the Cascade Mountains.

The general character of the electrical layout is similar to that used in Montana and Idaho, except as may be noted below:

Locomotive for passenger service will be of the G. E. bi-polar type, having a total weight of aproximately 265 tons and capacity sufficient to haul over the profile at a speed of approximately 25 miles per hour a twelve-car passenger train weighing 960 tons. Delivery of these locomotives will commence in August. Locomotives for freight service will be provided by changing the gear ratio of the present passenger locomotives used on the Rocky Mountain and Missoula Divisions, and in place of the latter locomotives there will be provided for the Rocky Mountain and Missoula Divisions ten quill-type locomotives manufactured by the Westinghouse Electric & Manufacturing Company, having approximately the same weight and capacity as the bipolar motors just referred to.

Power will be supplied over two transmission lines, one running from the Long Lake plant of the Washington Water Power Company to the Taunton sub-station, and the other from the Snoqualmie plant of the Puget Sound Traction, Light & Power Company to Cedar Falls and Renton sub-stations, these lines connecting at the sub-stations mentioned with the railroad's high tension tie line. It is planned to have this section under electrical operation by October of this year.

The Long Island Railroad Electrification

In 1905 the Long Island Railroad Company began electric operation on a portion of their lines.

It was the first complete electric service on an extensive scale of a steam railroad and is still the most extensive example of multiple unit passenger train operation.

The Long Island is essentially a passenger line, serving the residential suburbs of New York city and a heavy excursion business to the seashore of Long Island.

A network of lines of the company covers the western end of the island within 30 miles of New York City and delivers heavy commuter and excursion travel to the New York and Brooklyn terminals.

The electrification covers practically this network, and within a radius of 30 miles contains 88 route miles with a total main line track mileage of 187 miles, giving a frequent and quick service without transfer from the heart of Manhattan and Brooklyn boroughs of New York City to the terminus of the commuter zone, and to several points on the seashore.

Steam operated express trains to the eastern end of the island are taken from the Pennsylvania Station by electric locomotives to Harold Avenue, Long Island City, at which point steam locomotives are attached. It is probable that in the near future electric locomotives will haul these through trains to Jamaica, which is a central point for the various lines. The freight service is still conducted by steam, and on some portions of the electrified system steam locomotives are used to operate both freight and through passenger trains.

The third-rail, a. c. d. c. system is used with 650 volts D. C. on the third rail and three-phase, 25-cycle at 11,000 volts on the transmission lines.

The power is obtained from the Pennsylvania Railroad power house located at Long Island City and is delivered to the Long Island transmission lines at 11,000 volts.

The 134 passenger cars ordered for the lines electrified in 1905 were of steel and differed only from the New York subway trains in platform construction and other minor parts. They are 41 ft. over body corner posts, with a total length over drawbars of 51 ft. 4 in., and are 8 ft. 8 in. wide over eaves, and weigh equipped 79,664 lb.

Five wooden express cars were also provided at this time, equipped with the standard type of motor and trailer truck and with the same electrical equipment as the above passenger cars. These cars, 52 ft. 5 in. over all in length and 9 ft. 9½ in. in width, weigh about 76,500 lb. They are equipped with standard A. R. A. couplers to enable them to haul the old standard steam baggage and express cars as trailers.

In anticipation of the opening of the Pennsylvania Station and the operation of electric trains between Jamaica and points beyond, orders were placed during 1909 and 1910 for 150 steel passenger, passenger and baggage cars and seven steel baggage cars. For the same reason, 50 steel passenger cars of the same type were built in 1908 but were not electrically equipped at that time, and were used in the steam service until needed later in electric service.