

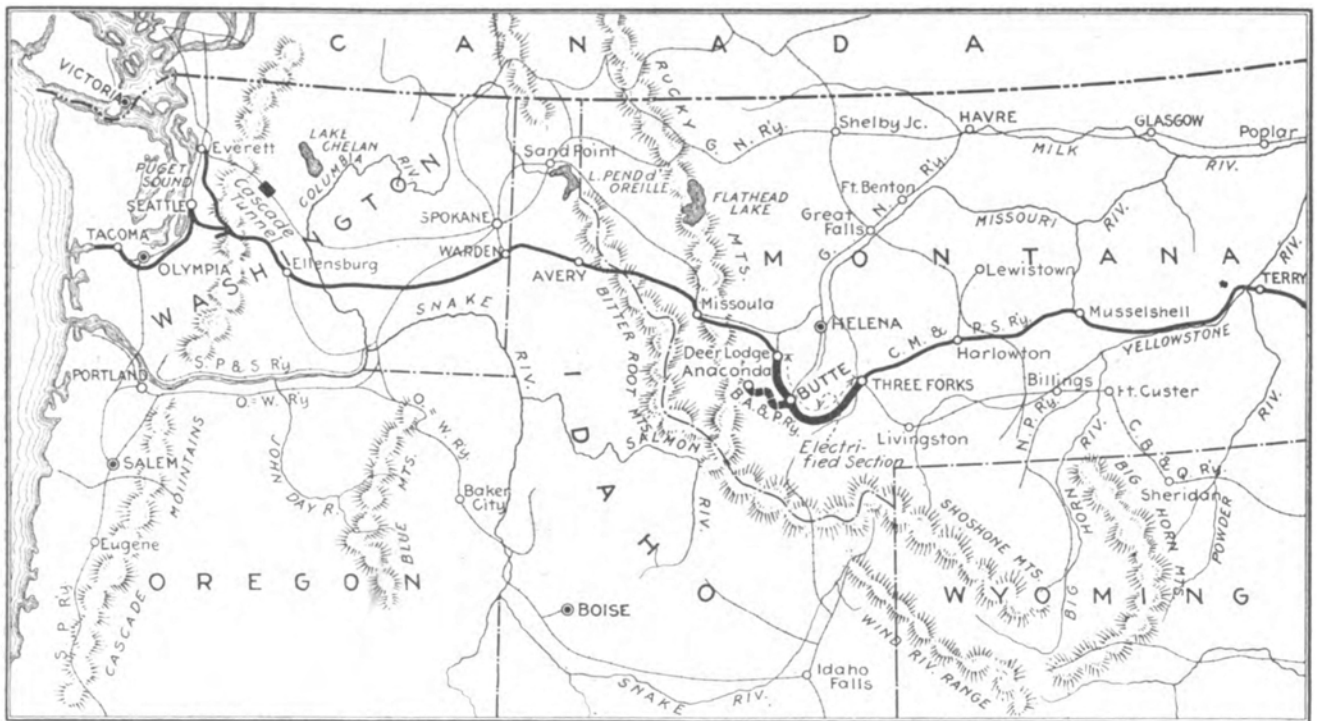
The Chicago, Milwaukee & St. Paul Electrification

The Final Plans Have Been Made and the Contracts Placed for the Electrification of 113 Miles of Trunk Line
—Locomotives Weighing 260 Tons and Using Regenerative Control Will Be Used—Four Substations
Will Supply 3000-Volt Direct Current to a Double Overhead Trolley Wire

With the placing, last week, of the contract for the electrical equipment for the Chicago, Milwaukee & St. Paul electrification there has been taken one of the most important steps in the history of the supersession of steam by electricity. In this instance electrical operation has been adopted, not because of the smoke nuisance, the high cost of terminals, the congestion of traffic, or any of the dozen other impelling but peculiarly local causes that have necessitated past installations, but rather because of the accumulated evidence as to the normal operating economies that may be expected from the use of the more modern form of motive power with low-priced hydroelectric energy.

labor and material necessary to complete the first 113-mile division will cost approximately \$3,000,000. It is also estimated that the complete electrification, comprising 440 miles, will cost approximately \$12,000,000, but the change in motive power is expected to result in a saving of 25 per cent over the costs involved by the present system of operation.

With regard to route mileage, this electrification is the first step in a scheme which, when completed, will very greatly exceed anything that has heretofore been attempted. The immediate program calls for the electrification of 113 miles of line between Three Forks and Deer Lodge, Mont., as shown in the accompanying map.



C., M. & ST. P. ELECTRIFICATION—MAP NORTHWESTERN SECTION OF THE UNITED STATES SHOWING ELECTRIFIED DIVISION

In authorizing the statement that the final contract for the work had been closed, C. A. Goodnow, assistant to the president in charge of construction, Chicago, Milwaukee & St. Paul Railway, said that field work on the overhead line would be started as soon as forces could be organized. Practically all of the poles are on the ground at the present time, and the overhead line material will be available as rapidly as it is required. The contract calls for the delivery of the first substation equipment on May 1, 1915, and the first locomotive on Oct. 1, 1915. Upon receipt of the first locomotive it is planned to run an operating test, and, if this is satisfactory, the electrified division will be in full operation by Jan. 1, 1916.

The contract for electrical apparatus, which was placed with the General Electric Company, covers the equipment for four substations, the overhead line materials and twelve locomotives. It is estimated that the

This, with sidings, makes a total single-track mileage of 168. The plans for the near future, however, include the extension of the electrified zone to cover 440 route-miles between Harlowtown, Mont., on the east, and Avery, Idaho, on the west, the whole foreshadowing the ultimate electrification of the main line to the Pacific Coast, a distance of 865 miles.

OVERHEAD CONSTRUCTION

Power for propulsion will be furnished at 3000 volts, d.c., and it is obvious that the remarkable success of the 2400-volt electrification of the Butte, Anaconda & Pacific Railroad, which, as shown by the map, is in the same general locality as the proposed electrified division, contributed largely to this choice of system. In fact, the overhead construction is to be exactly similar to that used on the Butte, Anaconda & Pacific Railroad, except that a double trolley wire of No. 0000

copper will be used in order to provide greater collection area for the pantograph shoes. The contact wires will be supported by a flexible catenary construction that will be hung from mast arms on wooden poles, the single-pole bracket construction having been adopted because it affords a minimum obstruction to the view and also is less expensive than the use of span wires. Double poles with span wire, however, will be employed where there are two or more tracks as well as at the sharper curves.

A limited amount of feeder copper will be placed on the poles at the present time to minimize the voltage drop between substations. A high-tension transmission line will also be installed along the right-of-way, tying the substations together. This line will be erected and maintained by the railroad company, independently of the transmission lines from the hydroelectric company which is to supply the power, and it will form a ring system to protect against shut-downs through line failures.

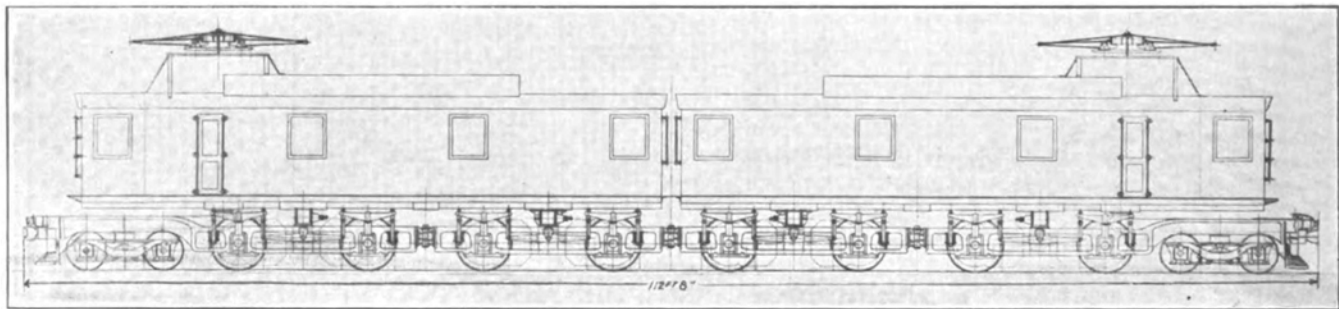
The prime power will be purchased from various hydroelectric plants of the Montana Power Company, and it will be transmitted to the railway company's substations at 110,000 volts, three phase, sixty cycles. The price at which it will be furnished approximates $\frac{1}{2}$ cent per kilowatt-hour, the power factor being limited to a variation of 20 per cent from unity and the monthly load factor being the equivalent of 60 per cent

high percentage being the high requirements for starting trains which reach momentary peaks of more than 5000 kw. These momentary loads will be easily carried, however, by the five-minute overload capacity of the motor-generator sets, which will be of the order of 200 per cent. The substations will be erected and placed in operation by the railway company, the General Electric Company furnishing all of the electrical machinery.

LOCOMOTIVES

The locomotives, of which twelve are to be included in the initial installation, are truly remarkable for their size and power. Each will consist of two half-units permanently coupled together to make an engine 112 ft. 8 in. long that weighs 260 tons and that has 200 tons on drivers. The prominent feature of the design is the use of a separate motor twin-gearred to each of the eight pairs of driving wheels. In the design may be seen the principle of "stretching out" the locomotive and thus minimizing the localization of vertical and horizontal blows on the track. The same principle was followed, although on a much smaller scale, in the case of the latest type of high-speed electric locomotive built by the General Electric Company for the New York Central Railroad, these engines having made a remarkably successful record for the past year in hauling the extremely heavy through passenger trains on that road.

The eight pairs of drivers for each complete loco-



C., M. & ST. P. ELECTRIFICATION—LOCOMOTIVE DIAGRAM SHOWING ARRANGEMENT OF DRIVING WHEELS AND MOTORS

when based on the contract load. As planned at present, the load factor will easily be maintained by requiring the dispatcher to adjust train movements so as not to exceed the maximum amount of power covered by the power contract.

SUBSTATIONS

Contrary to previous reports the high-tension alternating current will be transformed to 3000 volts d.c. in four permanent substations. These will be built of brick and will have concrete roofs that will provide a support for overhead high-tension busbars. Indoor transformers, of the self oil-cooled type, will step down the high-tension current to 2300 volts a.c. for use in motor-generator sets, each of the latter being composed of a synchronous motor mounted on the same shaft with two 1500-volt d.c. generators that are connected in series to supply 3000 volts to the line. Each unit will have two separate exciters for the synchronous motor and for the generator fields, and, with the control switchboard and transformers, will make a complete, independent set.

Two of the four substations that will be installed for the 113-mile division will contain equipments consisting of three 1500-kw motor-generator sets, and each of the other two substations will be equipped with two 2000-kw motor-generator sets. The total substation capacity will thus be 17,000 kw, or about 50 per cent of the input of all of the locomotives, the reason for this relatively

are equally spaced at about 10-ft. intervals. Each half-unit has two articulated trucks with frames outside of the driving wheels, and this arrangement, together with the connection between the half-units themselves provides a chassis composed of four trucks linked together by three permanent couplings. The driving-wheel trucks at the extreme ends of the complete unit have their frames extended to provide center-pin castings for four-wheeled bogie trucks, the extended framing carrying also the bumper beams and coupler at each end of the locomotive.

A summary follows of the general dimensions and weights of the locomotive:

Length face to face of couplers.....	112 ft. 8 in.
Total wheelbase.....	103 ft. 4 in.
Wheelbase each half unit.....	46 ft. 7 in.
Minimum driving wheelbase.....	5 ft. 0 in.
Total weight.....	260 tons
Weight on drivers.....	200 tons
Weight on each pair of driving wheels.....	25 tons
Weight on each bogie truck.....	30 tons
Diameter of driving wheels.....	52 in.
Capacity of locomotive—continuous rating.....	3000 hp
Capacity of locomotive—one-hour rating.....	3440 hp

The drivers are 52 in. in diameter and they are equalized in pairs on each side, so that each one of the four driving-wheel trucks is independent. The drivers on the end trucks are not excepted so that there is no cross equalization anywhere in the structure. Naturally each driving-wheel truck also has its own brake-rigging system. The bogie trucks at the ends of the complete unit are of the standard locomotive type with 36-in.

wheels on 6-ft. centers. Each one will transmit a 30-ton load to the truck wheels for guiding purposes, the truck center pin being 13 ft. 5 in. ahead of the nearest driving axle.

The cab extends practically the full length of the locomotive, the space between the two half-units being minimized to provide easy passageway from one end of the locomotive to the other. The height of the cab roof is only 13 ft. 10 in. above the rail exclusive of the housings for the ventilators, but the pantograph bases extend about 5 ft. above this owing to the great height of the trolley wire, which will be maintained at an elevation of about 24 ft. above the rail. The cab for each half-unit will be supported at two points, one permitting rotation and the other a sliding movement so that the chassis can weave about in accordance with the requirements of the track but without affecting the cab.

MOTORS AND CONTROL

The eight motors for the complete locomotive will be of the General Electric No. 253-A type, and each will have a continuous rating of 375 hp and a one-hour rating of 430 hp. This will give the locomotive a continuous rating of 3000 hp and an hourly rating of 3440 hp. The drawbar pull effective for starting trains will approximate 80,000 lb. As previously mentioned the motors will be twin-gearred to the driving axles, that is to say, each armature shaft will carry a pinion on each end, and it is only in the matter of gear ratio that the passenger locomotives will differ from those used for hauling freight.

The motors will be insulated for 3000 volts, but they will be permanently connected in pairs in series so that the voltage across each one will be 1500 when the locomotive is operating in full parallel on the 3000-volt trolley. The control will provide three running positions with the four pairs of motors connected in series, series-parallel or full-parallel, but the control system will include the novelty (for this country) of using regenerative braking control for holding trains on down grades. This will provide also for regenerative return of energy to the trolley wire on long down grades so that the presence of a train going down a mountain grade will be of assistance to another train coming up. This obviously will improve the load factor of the electrified division to a marked degree.

The motor equipment will enable locomotives in freight service to pull 2500-ton trains up 1 per cent grades at a speed of 16 m.p.h., or, when two locomotives are used on a train, will provide power enough to pull 2500 tons up a 2-per cent grade. However, the plan of operation includes the general use of a locomotive at each end of trains on ascending grades, there being one 2 per cent grade 20 miles long and two 1 per cent grades approximately 35 miles long on the electrified section. On descending grades only the locomotive at the head end will do the regenerative braking. The locomotives in passenger service will be called upon to haul trailing loads of 800 tons at a speed of 60 m.p.h. on the level.

Collection of the large drafts of current (ranging from 1500 amp to 2000 amp at 3000 volts) that will be required for the service at times will be effected through the use of two pantographs of the "pan" type on each complete locomotive. As a provision against the possibility of injurious arcing, however, and to supply an ample factor of surplus capacity the previously mentioned use of a double trolley wire was considered desirable. This secures flexibility and gives a greater area of collection, the maximum draft of current per pantograph contact being thus reduced to the order of 500 amp.

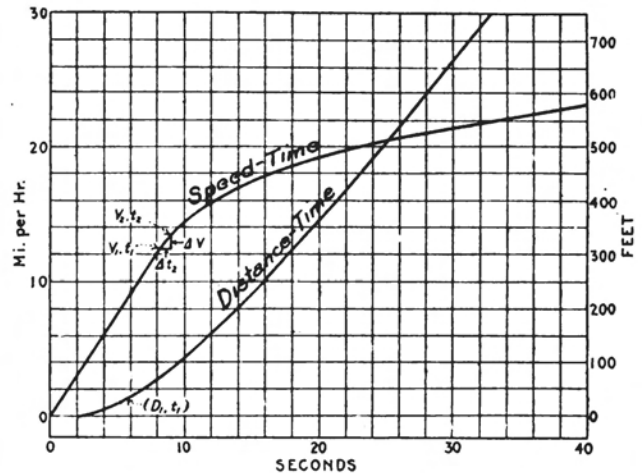
All of the plans for the electrification project have

been in charge of C. A. Goodnow, assistant to the president, Chicago, Milwaukee & St. Paul Railroad, and R. Beeuwkes, electrical engineer, and the work of construction that is soon to commence will be under their direction. In general, all of the erection will be done by the railroad company including the installation of the overhead lines, the construction of the substations, and the preliminary operation during the future period of transition from the use of steam to that of electricity.

Electric Railway Graphics at A. I. E. E. Meeting

Graphical Methods of Plotting Velocity-Time and Distance-Time Curves Were Considered at Last Week's Meeting

At the regular monthly meeting of the American Institute of Electrical Engineers, held in New York on Nov. 13, part of the time was devoted to the presentation and discussion of a brief paper on "A Graphic Method for Speed-Time and Distance-Time Curves," by E. C. Woodruff, of the electrical engineering faculty, Pennsylvania State College. This paper appears in the November issue of the A. I. E. E. *Proceedings*. The paper was discussed by C. O. Mailloux, N. W. Storer, Max von Recklinghausen, F. Castiglioni, and others. The general trend of the discussion indicated that the



RAILWAY GRAPHICS—FIG. 1

method outlined by the author was ingenious but that it had been used before substantially in the same form. The speakers emphasized the importance of graphical methods when many calculations are to be made. Mr. Mailloux described the methods which he had developed for applying the integraph, a special form of planimeter which traces an integral curve, to electric railway problem solution. The limitations of graphical methods in regard to accuracy were referred to in the discussion, especially in methods involving an accumulation of errors as the one just presented does.

Professor Woodruff's method of plotting time-speed, or as Mr. Mailloux prefers "velocity-time," curves is explained and illustrated briefly below:

In Fig. 1 are shown the curves which are desired; that is velocity-time and distance-time curves.

The velocity-time curve consists of two parts; a straight line from $V = 0, t = 0$ to $V_1 t_1$ where starting resistance has all been cut out, and a curved line from $V_1 t_1$ onward as current is cut down by increasing counter-emf.

The straight-line part of the curve is calculated by assuming starting current per motor and reading from the traction-current curve furnished by the motor manufacturer or experimentally determined, the traction