THE ELECTRIFICATION OF THE PUGET SOUND LINES OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

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The author gives a brief account of the scope of the work to be undertaken on this the most important of steam road electrifications. He gives a description of the power supply available, the cost of power to the railway company, the type of substation and rolling stock equipment, and the overhead construction to be adopted. It is of special interest to note that the trolley potential is to be 3000 volts, which is the highest direct-current potential yet adopted in this country for railway work.—Editor.

Plans for the electrification of the first engine division of the Chicago, Milwaukee & St. Paul Railway have now been completed and contracts have been let with the General Electric Company for electric locomotives, substation apparatus and line material, and with the Montana Power Company for the construction of transmission and trolley lines. The initial electrification of 113 miles of main line between Three Forks and Deer Lodge is the first step toward the electrification of four engine divisions extending from Harlowton, Montana, to Avery, Idaho, a total distance of approximately 440 miles with approximately 650 miles of track, including yards and sidings. While this comprises the extent of track to be equipped in the near future, it is understood that plans are being made to extend the electrification from Harlowton to the Coast, a distance of 850 miles, should the operating results of the initial installation prove as satisfactory as anticipated.

The plans of the Chicago, Milwaukee & St. Paul Railway are of especial interest, as this is the first attempt to install and operate electric locomotives on tracks extending over several engine divisions, under which conditions it is claimed the full advantage of electrification can be secured. The various terminal and tunnel installations made in the past have been more or less necessary by reason of local conditions, but the electrification of the Chicago, Milwaukee & St. Paul is undertaken purely on economic grounds with the expectation that superior operating results with electric locomotives will effect a sufficient reduction in the present cost of steam operation to return an attractive percentage on the large investment required. If the savings anticipated are realized in the electric operation of the Chicago, Milwaukee & St. Paul Railway, this initial installation will constitute one of the most important mile-stones in electric railway progress, and it should foreshadow large future developments in heavy steam road electrification. The success of electric operation on such a large scale will at least settle the engineering and economic questions involved in making such an installation, and will limit the future problems of electrification to the ways and means of raising the required capital to effect the change in motive power.

The first step taken towards electrification by the Chicago, Milwaukee & St. Paul Railway was to enter into a contract with the Montana Power Company for an adequate supply of power over the 440 miles of main line considered for immediate electrification. The precautions taken both by the Railway Company and Power Company to safeguard the continuity of power supply should guarantee a reliable source of power, subject to few interruptions of a momentary nature only.

The Montana Power Company covers a great part of Montana and part of Idaho with its network of transmission lines which are fed from a number of sources of which the principal are tabulated below:

Madison River	11,000 kw.
Canyon Ferry	7,500 kw.
Hauser Lake	14,000 kw.
Big Hole	3,000 kw.
Butte, steam turbine	5,000 kw.
Rainbow Falls	21,000 kw.
Small powers aggregating	7,390 kw.
Total power developed	68,890 kw.

Further developments part of which are under construction are as follows:

Great Falls	85,000 kw.
Holter	30,000 kw.
Thompson Falls	30,000 kw.
Snake River	20,000 kw.
Missoula River	10,000 kw.
Total power undeveloped	175,000 kw.

Total power capacity developed and undeveloped, 244,000 kw.

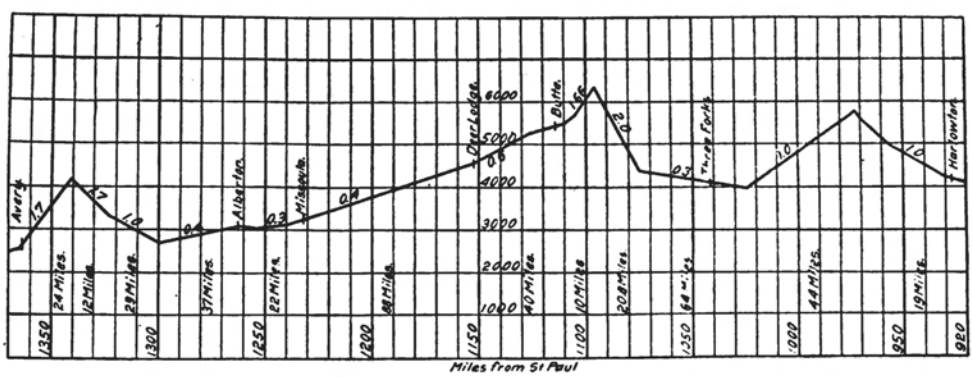
The several power sites are interconnected by transmission lines; the earlier ones are supported on wooden poles and operate at 50,000 volts and the later installations are supported on steel towers and operate at 100,000 volts. Ample water storage capacity (300,000 acre-feet), is provided in the Hebgen Reservoir and this is supplemented by auxiliary reservoir capacity at the several power sites which brings the total up to 418,000 acre-feet. The Hebgen Reservoir is so located at the head waters of the Madison River that water drawn from it can supply in turn the several installations on the Madison and Missouri rivers, so that the same storage water is used a number of times, giving an available storage capacity considerably greater than is indicated by the figures given. It would seem, therefore, in changing from coal to electricity as a source of motive power, that the railroad is amply protected as regards reliability and continuity of power supply.

Due to the great facilities available and the low cost of construction under the favorable conditions existing, the Railway Company will purchase power at a contract rate of 0.536 cents per kilowatt-hour, based upon a 60 per cent load-factor. It is expected under these conditions that the cost of power for locomotives will be considerably less than is now expended for coal. The contract between the Railway and Power Companies provides that the total electrification between Harlowton and Avery, comprising four engine divisions, will be in operation by January 1, 1918.

In order to connect the substations with the several feeding-in points of the Montana Power transmission lines, a tie-in transmission line is being built by the Railway Company which will permit feeding each substation from two directions and from two or more sources of power. This transmission line will be constructed with wooden poles and suspension type insulators, and will operate at 100,000 volts. It will follow in general the right of way of the Railway Company, except where advantage can be taken of a shorter route over public domain to avoid the necessarily circuitous line of the railway in the mountain districts.

The immediate electrification of 113 miles will include four substations containing step-down transformers and motor-generator sets with the necessary controlling switchboard apparatus to convert 100,000 volts, 60 cycles, three-phase power to 3000 volts direct current. This is the first direct-current installation using such a high potential as 3000 volts, and this system was adopted in preference to all others after a careful investigation extending over two years. The 2400-volt direct-current installation of the Butte, Anaconda & Pacific Railway in the immediate territory of the proposed Chicago, Milwaukee & St. Paul electrification has furnished an excellent demonstration of high-voltage direct-current-locomotive operation during the past year and a half, and the selection of 3000 volts direct current for the Chicago, Milwaukee & St. Paul Railway was due in a large measure to the entirely satisfactory performance of the Butte, Anaconda & Pacific installation.

The equipment for this road was also furnished by the General Electric Company, and a comparison based on six months steam and electric operation shows a total net saving of more than 20 per cent on the investment or total cost of electrification. These figures of course do not take into



Profile of Section of the Chicago, Milwaukee & St. Paul undergoing Electrification

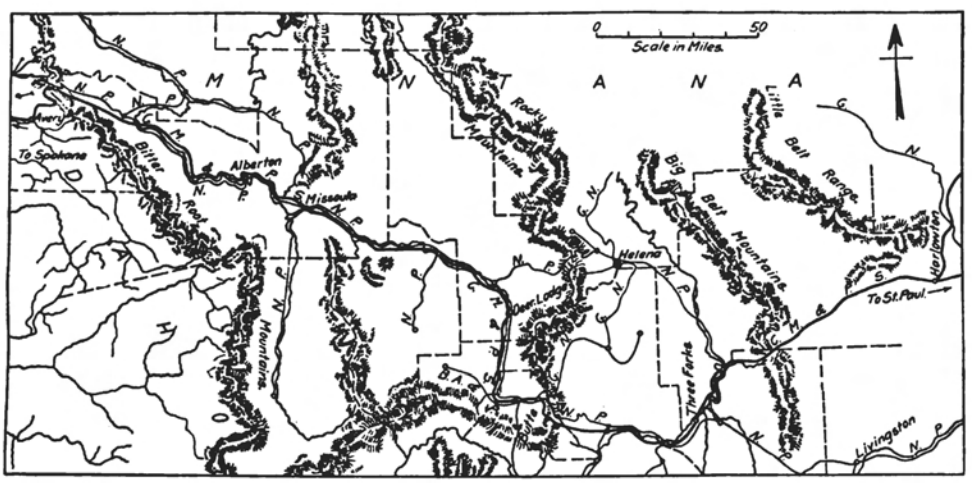
account the increased capacity of the lines, improvement to the service, and the more regular working hours for the crews. The comparison also shows that the tonnage per train has been increased by 35 per cent, while the number of trains has been decreased by 25 per cent, with a saving of 27 per cent in the time required per trip.

Substations

The substation sites of the Chicago, Milwaukee & St. Paul Railway electrified zone provide for an average intervening distance of approximately 35 miles, notwithstanding that the first installation embraces 20.8 miles of two per cent grade westbound and 10.4 miles of 1.66 per cent grade eastbound over the main range of the Rocky Mountains. With this extreme distance between substations and considering the heavy traffic and small amount of feeder copper to be installed, it becomes apparent that such a high potential as 3000 volts direct current permits of a minimum investment in substation apparatus and considerable latitude as to location sites.

The substations will be of the indoor type, the transformers being three-phase, oil-cooled, with 100,000-volts primary and 2300 volts secondary windings. The synchronous motors will operate at the latter potential. The transformers will be rated 1900 and 2500 kv-a. and will be provided with four 2½ per cent taps in the primary, and 50 per cent starting taps in the secondary.

The motor-generator sets will comprise a 60-cycle synchronous motor driving two 1500-volt direct-current generators connected permanently in series for 3000 volts. The fields of both the synchronous motors and direct-current generators will be separately excited by small generators direct-connected to each end of the motor-generator shaft. The direct-current generators will be compound wound and will maintain constant potential up to 150 per cent load and will have a capacity for momentary overloads up to three times their normal rating. To insure good commutation on these overloads the generators are equipped with commutating poles and compensating pole face windings. The synchronous motors will also be utilized as synchronous condensers and it is expected that the transmission line voltage can be so regulated thereby as to eliminate any effect of the fluctuating railway load.



Map showing Section of the Chicago, Milwaukee & St. Paul to be Electrified

The location and equipment of the several substations is as follows:

Morel, two 2000-kw. motor-generator sets; Janey, three 1500-kw. motor-generator sets; Piedmont, three 1500-kw. motor-generator sets; and Eustis, two 2000-kw. motor-generator sets.

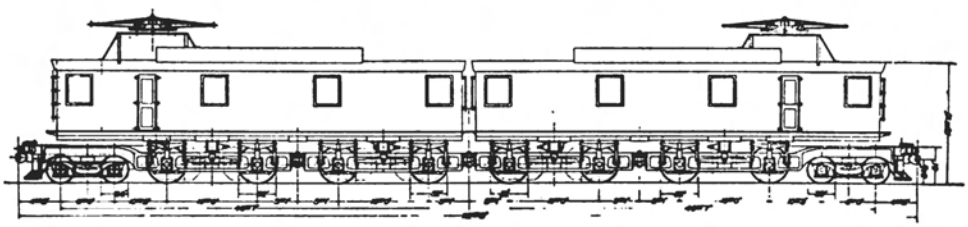
Overhead Construction

Trolley construction will be of the catenary type in which a 4/0 trolley wire is flexibly suspended from a steel catenary supported on wooden poles, the construction being "bracket" wherever track alignment will permit and "cross span" on the sharper curves and in the yards. Steel supports instead of wooden poles will be used in yards where the number of tracks to be spanned

exceeds the possibilities of wooden pole construction. Poles for the first installation are already on the ground and 30 miles of poles are set. Work in this direction will be pushed with all speed and will be completed ready for operation in the fall of 1915, on the delivery of the first locomotives.

As the result of careful investigation and experiments a novel construction of trolley will be installed composed of the so-called twin-conductor trolley. This comprises two 4/0 wires suspended side by side from the same catenary by independent hangers alternately connected to each trolley wire. This form of construction permits the collection of very heavy currents by reason of the twin contact of the pantograph with the two trolley wires and also insures sparkless collection under the extremes of either heavy current at low speed or more moderate current at very high speeds. It seems that the twin-conductor type of construction is equally adapted to the heavy grades, calling for the collection of very heavy currents, and on the more level portions of the profile where maximum speeds of 60 m.p.h. will be reached with the passenger trains having a total weight of over 1000 tons. The advantage of this type of construction is due partly to the greater surface for the collection of current, and partly to the very great flexibility of the alternately suspended trolley wires, a form of construction which eliminates any tendency to flash at the hangers either at low or high speed. Including sidings, passing and yard tracks, the 113 miles of route-mileage is increased to approximately 168 miles of single track to be equipped between Deer Lodge and Three Forks in the initial installation.

The locomotives to be manufactured by the General Electric Company are of special interest for many reasons. They are the first locomotives to be constructed for railroad service with direct-current motors designed for so high a potential as 3000 volts. They will weigh approximately 260 tons and will have a continuous capacity greater than any steam or electric locomotive yet constructed. Perhaps the most interesting part of the equipment is the control, which is arranged to effect regenerative electric braking on down grades. This feature as yet has never been accomplished with direct-current motors on so large a scale. The general characteristics are tabulated below.



Outline of 260-Ton Electric Locomotive for the Chicago, Milwaukee & St. Paul Railway

Total weight	260 tons
Weight on drivers	200 tons
Weight on each guiding truck	30 tons
Number of driving axles	8
Number of motors	8
Number of guiding trucks	2
Number of axles per guiding truck	2
Total length of locomotive	112 feet
Rigid wheel-base	10 feet
Voltage of locomotive	3000
Voltage per motor	1500
H.P. rating one hour—each motor	430
H.P. rating continuous—each motor	375
H.P. rating one hour—complete locomotive	3440
H.P. rating continuous—complete locomotive	3000
Trailing load capacity, two per cent	1250 tons
Trailing load capacity, one per cent	2500 tons
Approximate speed at these loads and grades	16 m.p.h.

The Chicago, Milwaukee & St. Paul Railway, from Harlowton to the Coast crosses four mountain ranges. The Belt Mountains at an elevation of 5768 feet, the Rocky Mountains at an elevation of 6350 feet, the Bitter Root Mountains at an elevation of 4200 feet and the Cascade Mountains at an elevation of 3010 feet. The first electrification between Three Forks and Deer Lodge calls for locomotive operation over 20.8 miles of two per cent grade between Piedmont and Donald at the crest of the main Rocky Mountain Divide, so that the locomotives will be fully tested out as to their capacity and general service performance in overcoming the natural obstacles of the first engine division. The initial contract calls for nine freight and three passenger locomo-

tives having the above characteristics. The freight and passenger locomotives are similar in all respects except that the passenger locomotives will be provided with a gear ratio permitting the operation of 800 tons trailing passenger trains at approximately 60 m.p.h., and will furthermore be equipped with an oil-fired steam-heating outfit for the trailing cars. The interchangeability of all electrical and mechanical parts of the freight and passenger electric locomotives is considered to be of very great importance from the standpoint of operation and maintenance.

The cab consists of two similar sections extending practically the full length of the locomotive. Each section is approximately 52 feet long and the cab roof is about 14 feet above the rail exclusive of housings for the ventilation. The trolley bases are about five feet about the roof owing to the unusual height of the trolley wire which will be located at a maximum elevation of 25 feet above the rail. The outer end of each cab will contain a compartment for the engineer while the remainder is occupied by the electric control equipment, train heater, air-brake apparatus, etc.

Motors

The eight motors for the complete locomotive will be Type GE-253-A. This motor has a normal one-hour rating of 430 h.p. with a continuous rating of 375 h.p. The eight motors will thus give the locomotive a one-hour rating of 3440 h.p. and a continuous rating of 3000 h.p. which makes it more powerful than any steam locomotive ever built. The tractive effort available for starting trains will approximate 120,000 lb. at 30 per cent coefficient of adhesion.

Each motor will be twin-geared to its driving axle in the same manner as on the Butte, Anaconda & Pacific, the Detroit River Tunnel and the Baltimore and Ohio locomotives, a pinion being mounted on each end of the armature shaft. The motor is of the commutating-pole type and has openings for forced ventilation from a motor-driven blower located in the cab.

The freight locomotives are designed to haul a 2500-ton trailing load on all gradients up to one per cent at a speed of approximately 16 m.p.h., and this same train load, unbroken, will be carried over the 1.66 and two per cent ruling grades on the west and east slope of the Rocky Mountain Divide with the help of a second similar freight locomotive acting as a pusher. Track provision is being made at Donald, the summit of the grade, to enable the pusher locomotive to run around the train and be coupled to the head end to permit electric braking on down grade. In this case the entire train will be under compression and held back by the two locomotives at this head end, the entire electric braking of the two locomotives being under the control of the motorman in the operating cab of the leading locomotive. It is considered that electric braking will prove very valuable in this mountain railroading, as in addition to providing the greatest safety in operation, it also returns a considerable amount of energy to the substations and transmission system which can be utilized by other trains demanding power. In this connection, the electric locomotives will have electric braking capacity sufficient to hold back the entire train on downgrades, leaving the air-brake equipment, with which they are also equipped, to be used only in emergency and when stopping the train. There is therefore provided a duplicate braking system on down grades which should result in safety of operation, and should eliminate breakdowns, wheel and track wear and overheating, as well as leading to a reduction in maintenance and an improvement in track conditions.

With the completion of the remaining engine divisions it is proposed to take advantage of the possibilities afforded by the introduction of the electric locomotive by combining the present four steam-engine divisions into two locomotive divisions of approximately 220 miles length; changing crews, however, at the present division points. As the electric locomotive needs inspection only after a run of approximately 2000 miles, requires no stops for taking on coal or water, or layover due to dumping ashes, cleaning boilers or petty roundhouse repairs, it is expected that the greater flexibility of the locomotive so provided will result in considerable change in the method of handling trains now limited by the restrictions of the steam engine.

The electrification of the Chicago, Milwaukee & St. Paul Railway is under the direction of Mr. C. A. Goodnow, Assistant to the President in charge of construction, and the field work is under the charge of Mr. R. Beeuwkes, Electrical Engineer of the railway.