
Over the Mountains
by Electric Power
THE
CHICAGO
MILWAUKEE
AND ST. PAUL
RAILWAY


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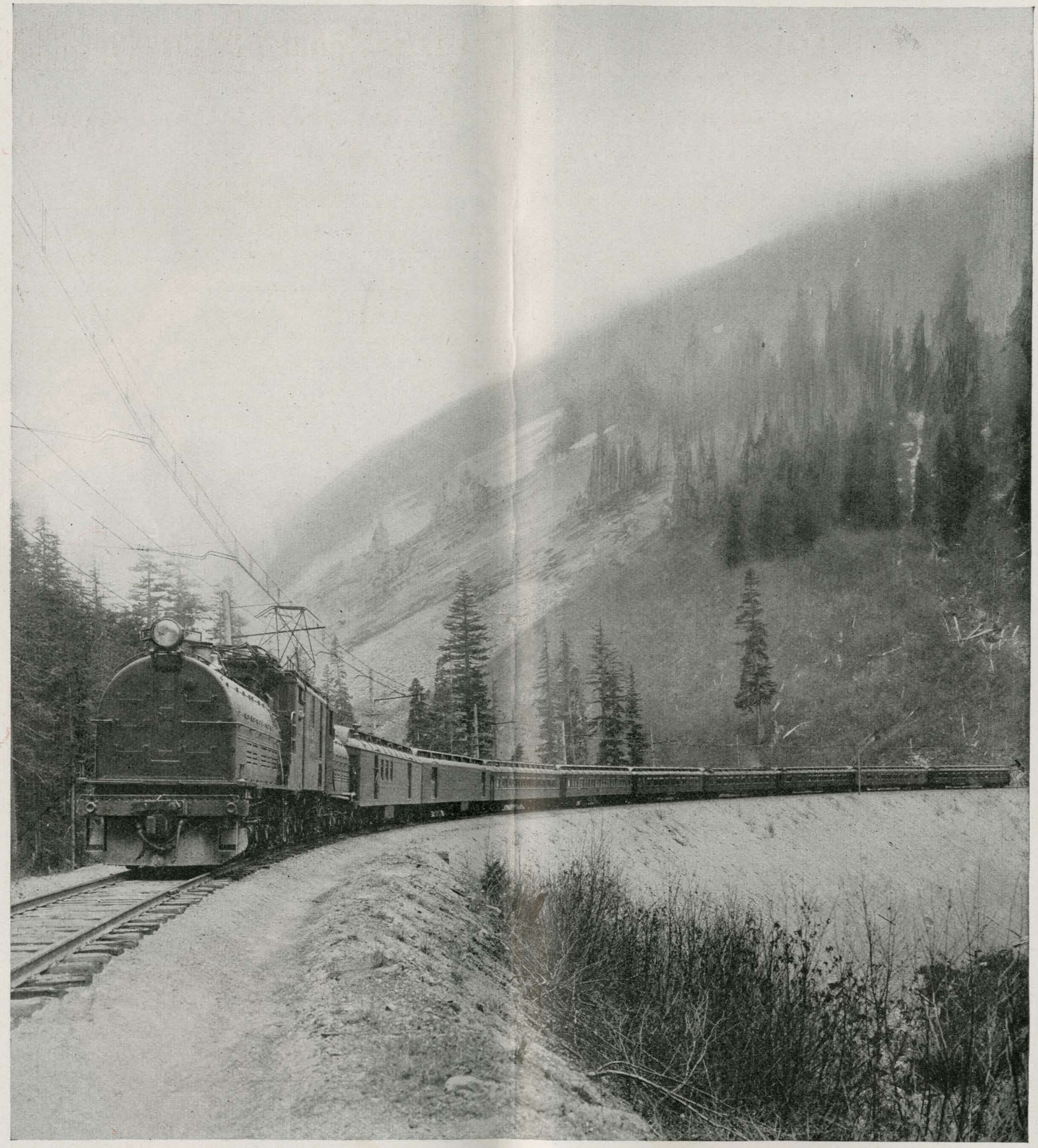


THE "OLYMPIAN" IN THE CASCADES

Electrification of the Transcontinental Line
of the
Chicago, Milwaukee & St. Paul Railway

The progress in electrification accomplished by the Chicago, Milwaukee and St. Paul Railway is the greatest single step made in this field in any part of the world. In many ways, this work has been unique in the history of the application of electricity to the haulage of main line trains. With the exception of the Butte, Anaconda & Pacific Railway, no other heavy traffic road has turned to electricity solely for the purpose of reducing operating costs and for expediting traffic over its lines. In the earlier projects like the Baltimore & Ohio Belt Line electrification, the Cascade Tunnel on the Great Northern Railway, the New York, New Haven and Hartford and the New York Central lines entering New York City, the Hoosac Tunnel section of the Boston & Maine Railroad and others, electrification has been undertaken as a necessity because of tunnel and terminal operation which made the use of steam locomotives extremely objectionable, if not impossible.

On no other steam road are electric locomotives used over more than one division. The full economies of electrical operation, therefore, have not previously been demonstrated because of the necessary duplication of steam and electrical equipments.

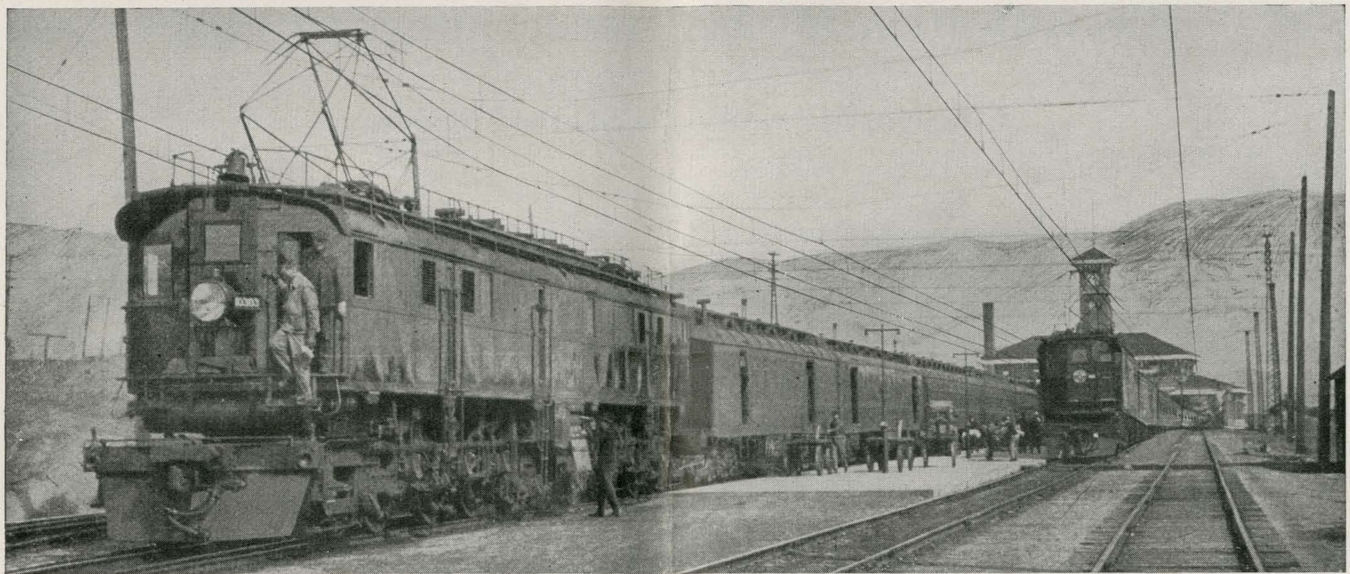
The initial electrification of the Chicago, Milwaukee & St. Paul Railway included the conversion of four steam engine divisions extending from Harlowton, Montana, to Avery, Idaho, a distance of 440 miles. This distance is approximately equal to that from New York to Buffalo and is more than six times as great as any trunk line now operating electric locomotives. Electric service was started during the month of December, 1915, and was gradually extended over the entire Rocky Mountain and Missoula divisions, steam engines being entirely superseded about a year later. At this time there were 42 main line freight and passenger locomotives in operation and two switching locomotives, the former handling in 1918 an amount of traffic which would have required about 120 steam locomotives of the various types displaced.

The tracks of this system, in traversing the Rocky Mountain district, include many long grades and short radius curves. In crossing the three mountain ranges, there are several grades of one per cent or more, the most difficult of which is the 21-mile, two per cent grade between Piedmont and Donald and the longest, the 49 mile, one per cent grade ascending the west slope of the Belt Mountains. The maximum curvature is 10 degrees and there are many sections where this maximum is reached. There are also numerous tunnels in the electric zone, 36 in all, the longest being the St. Paul Pass Tunnel, over 1½ miles in length, piercing the ridge of the Bitter Root Mountains. In the winter, the heavy snows in the Bitter Root Mountains make the problem of train movement most difficult, and winter temperatures as low as—40 degrees Fahr. caused serious delays under steam operation owing to engine failure or inability to make steam.

Coast Division

On the completion of the electrification on the Rocky Mountain and Missoula divisions early in the year 1917, the railroad began the electrifying of an additional 207 miles of main line, comprising the present Coast Division, which extends from Othello, Wash., to Seattle and Tacoma, and crosses the Saddle Mountains just west of the Columbia River and the Cascade Mountains. The general character of this electric layout is similar to that of the former district.

Pusher service was inaugurated in the Fall of 1919 with freight locomotives on the heavy grades and passenger service was started in March, 1920. In general, the same type of equipment was used as on the original



THE "OLYMPIAN" AND "COLUMBIAN" AT THE BUTTE, MONTANA PASSENGER STATION

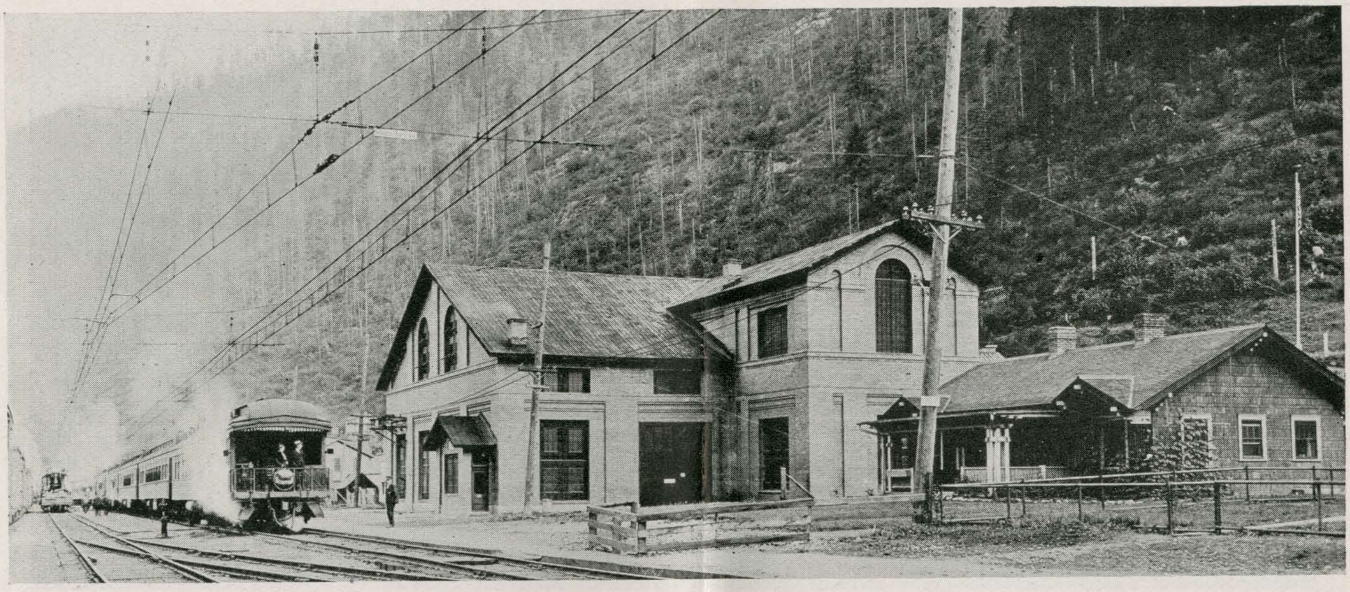
electrification with the exception of the passenger locomotives which are of the gearless type instead of the geared units as used on the initial electrification and which were equipped with suitable gearing for freight service and transferred to the Coast Division, ten new quill-type geared locomotives supplanting them in passenger service on the Rocky Mountain and Missoula divisions. The profile of the Coast Division includes many severe grades and a number of tunnels crossing the Cascade Ranges. Westbound, there is a 17-mile, 2.2 per cent grade extending from Beverly Junction to Boylston, and, eastbound, a 20-mile, 1.74 per cent grade from Cedar Falls to the summit of the Cascades.

Experience with electrical operation through the Bitter Root Mountains convinced the Railway Company that electrification of the tracks over the Cascade Range would greatly reduce the delays during winter running due to cold weather and lack of sufficient motive power to drive through the deep snows. On this division, fuel oil was used for all locomotives and the conservation of this fuel by the use of hydro-electric power is of national importance.

Freight traffic comprises from four to six trains daily in each direction. The larger part of this traffic is through freight—trains being made up of an assortment of foreign cars including box and flat cars, coal and ore hoppers, stock cars, refrigerators, etc., varying in weight from 11 to 25 tons empty, and as high as 70 tons loaded. Since these cars are owned by many different railway systems, they are equipped with air brakes adjusted for different conditions of operation and in accordance with different standards as to braking power and type of equipment, thus making the problem of holding the long trains on down grades by use of air brakes a most difficult one.

Electrical Operation

The electrical operation with both passenger and freight trains on these two districts has produced operating results fully equal to the expectations of the advocates of the electrification project. The capabilities of the electric locomotive for heavy grade service have been amply demonstrated and the two per cent, 20-mile grade over the Rocky Mountains no longer limits the capacity of the road. Congestion of freight traffic has been eliminated by increasing the weight of trains and also the speed of trains hauled over this section. Freight trains of 3,000 tons trailing are now handled eastward over a 1.66 per cent grade



THE "OLYMPIAN" ON ITS WAY ACROSS THE DIVIDE

and 2,800 tons westward over a 2 per cent grade, a helper being used in both cases on the heavy grade.

The new passenger locomotives are designed to handle a train weighing 960 tons or an average of about 12 all-steel cars over the entire profile of road without a helper. During the early part of the electrical operation, a local train in each direction was operated daily between Harlowton and Deer Lodge. This train was subsequently taken off and the transcontinental passenger trains have since been required to make local stops, the running time being slightly increased to allow for the increased number of stops.

During the winter period, the electric locomotives have shown themselves especially serviceable, delays due to low temperatures being eliminated, and in the Bitter Roots, where the deep snows cause much trouble, electrical operation has proved much more reliable than steam. Under electrical operation, the locomotives, instead of being changed at the end of each engine division of about 110 miles, can remain in service continually, with a light inspection at the two ends of the electrified territory or until called into shop for general inspection or repairs.

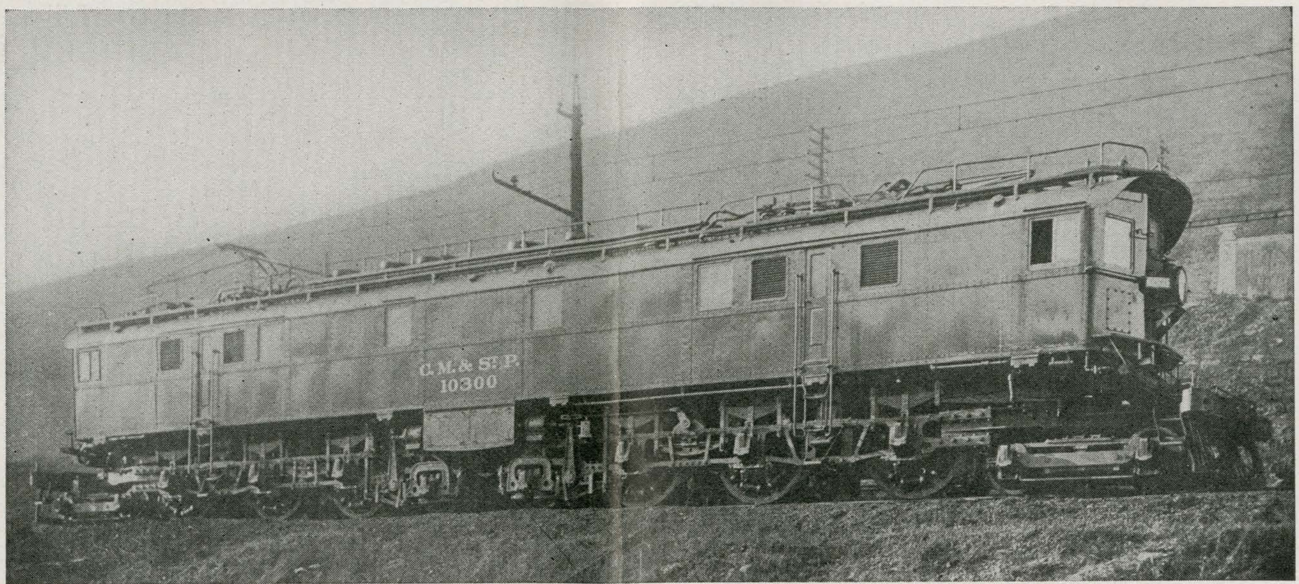
During the first few months of operation, the late Mr. C. A. Goodnow, Vice-President of the Chicago,

Milwaukee & St. Paul Railway, in charge of the electrification, said:

"Our electrification has been tested by the worst winter in the memory of modern railroaders. There were times when every steam locomotive in the Rocky Mountain district was frozen, but the electric locomotive went right along. Electrification has in every way exceeded our expectations. This is so, not only as respects tonnage handled and mileage made, but also the regularity of operation."

Regeneration

Regeneration, or the recovery of energy on the descending grades, by reversing the function of the electric motors, reduces the cost of operation and furnishes a ready solution of the difficult braking problem. On the long sustained grades, encountered in crossing the several mountain ranges, great skill is required to handle either the heavy and varied freight or the high-speed passenger trains with the usual air brakes. The entire energy of the descending train must be dissipated by the friction of the brake shoes on the wheels. This energy approximates 3,500 kw. or 4,700 h.p. for a 2,500-ton train running at 17 miles per hour down a 2 per cent grade, thus



QUILL SPRING DRIVE PASSENGER LOCOMOTIVE

explaining why brake shoes frequently become red hot and other serious damage is done.

With regenerative braking, the motors become generators, which absorb the energy of the descending train and convert it into electricity, thus restricting the train to a safe speed down the grade and, at the same time, returning electric power to the trolley for use by other trains. The strain on draw-bars and couplings is reduced to a minimum since the entire train is bunched behind the locomotive and held to a uniform speed. The electric-braking mechanism automatically controls the speed by regulating the amount of energy fed back to the line. This smooth and easy descent is in marked contrast to the periodical slowing down and speeding up of a train controlled by air brakes.

The usual speed of the electrically hauled freight train is 15 miles per hour ascending and 17 miles per hour descending the maximum grade, but half these speeds can easily be maintained with series connections of the motors should conditions require it.

In case there are no other trains between the substations to absorb the power generated by a descending train, this power passes through the substation machinery, is converted from direct to alternating

current and fed into the distribution system connecting all substations. The Power Company's lines are so extensive and the load of such a diversified character that any surplus power returned by regenerating locomotives can readily be absorbed by the system. Credit is given for all energy returned.

The advantages of regenerative braking may be summarized as follows:

Elimination of difficulties incident to the use of air brakes on heavy freight trains when descending mountain grades.

Elimination of brake shoe and wheel wear with resultant reduction in maintenance.

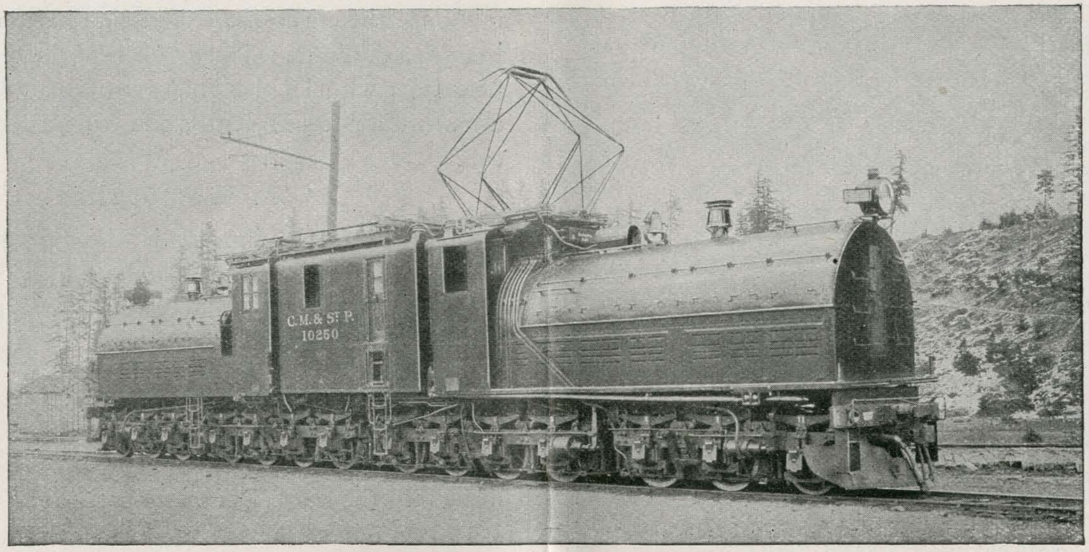
Reduced wear on tracks, especially on severe curves.

A saving of approximately 12 per cent in the total power consumption.

Maximum safety in operation assured by a duplicate braking system relieving the air brakes.

The absence, except at stopping, of grinding of the brakes which is especially disagreeable on a heavy passenger train.

Increased comfort to passengers and reduced wear and tear on freight equipment, owing to uniform speed on grades.



BI-POLAR GEARLESS PASSENGER LOCOMOTIVE

Electrical Equipment

The Chicago, Milwaukee & St. Paul electrification is operated entirely by hydro-electric power generated at the several plants of the Montana Power Company in Montana, and at the Washington Water Power and the Puget Sound Traction, Light and Power companies in Washington. Energy is transmitted from the point of purchase over the Railway Company's transmission lines at 100,000 volts, 3 phase, 60 cycles A. C. to the several substations and converted to 3,000 volts direct current for distribution over a catenary trolley system.

Motive Power

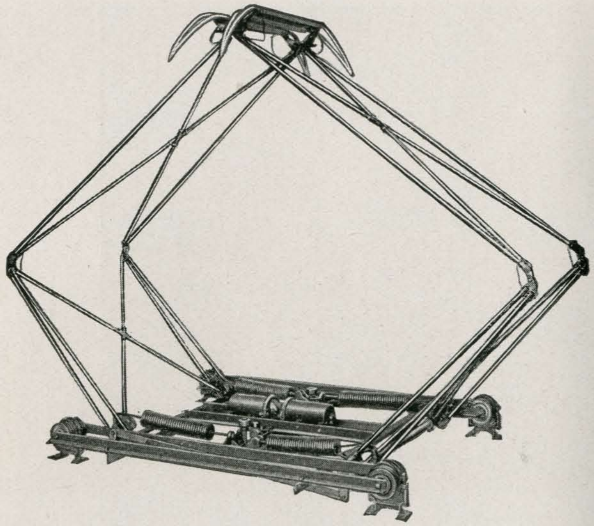
The main line locomotives furnished for the initial 440-mile electrification in Montana were of uniform design except that 30 units were geared for freight and 12 for passenger speeds. The passenger units were also equipped with oil-fired steam boilers for train heating. This type of engine, however, was distinctly a freight design and as previously stated, all have now been changed over for freight service. To replace the original passenger engines and to handle passenger trains on the two electrified districts, 15 new passenger locomotives were purchased, making the complete motive power for the Electric Zones as follows:

Type	Weight Tons	No.	Date Put in Service	Manufacturer
Main line freight....	288	42	1916–17	G. E. Co.
Main line passenger.	260	5	1920	G. E. Co.
Main line passenger.	283	10	1920	W. E. & M. Co.
Switchers..........	70	2	1917–18	G. E. Co.
Switchers..........	70	2	1919–20	G. E. Co.
Total.........		61		

Electric Freight Locomotives

The main line freight locomotives are constructed in two units, permanently coupled together, the halves being duplicates, each capable of independent operation.

This feature has been taken advantage of by the Railway Company and a few of these units have from time to time, been separated into half-units supplied with suitable drawbars and couplers for use in light freight service and on construction trains. The main line electric locomotive in freight service has a total weight of 288 tons, a starting tractive force of 136,000 pounds, and is capable of sustaining continuously a tractive force of 70,700 pounds at a speed of 15.9 miles per hour. These figures are contrasted to the capacity of the heavy Mallet steam locomotive weighing, with tender, 278 tons, which has a maximum tractive force



SLIDING PANTOGRAPH TROLLEY

at starting of 76,200 pounds, but is capable of sustaining its tractive force at only half that speed. There are 26 main line freight locomotives on the Montana divisions and 16 similar units on the Cascade Division. These locomotives are the first to be operated at a potential as high as 3,000 volts and the first to use direct-current regeneration. The freight locomotives haul a 2,500-ton trailing train at a speed of approximately 16 m.p.h. on all grades up to and including one per cent. On two per cent grades, the trailing load was originally limited to 1,250 tons, although this figure has been increased to 1,400 tons in actual operation.

Motors and Control

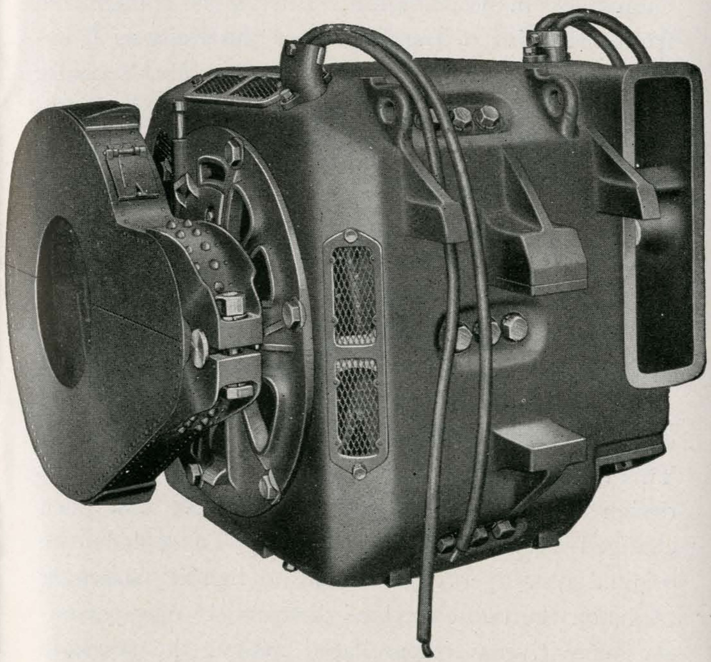
The freight locomotives are equipped with eight, type GE-253-A, 1,500-volt motors insulated for 3,000 volts to the ground. Each motor has a one hour rating of 430 h.p. and a continuous rating of 375 h.p., making a normal rating for the locomotive of 3,440 h.p. and a continuous rating of 3,000 h.p.

Each motor is twin geared to its driving axle in the same manner as on the Butte, Anaconda & Pacific, Detroit River Tunnel and Baltimore & Ohio locomotives, a pinion being mounted on each end of the armature shaft. Ample flexibility is obtained by the use of a spring gear and a spring nose suspension which

minimize the effect of all shocks and also reduce gear wear to a minimum. The motor is of the commutating pole type with longitudinal ventilating ducts in the armature for forced ventilation from a blower in the cab.

Control Equipment

The control equipment is the Sprague General Electric Type "M" arranged for multiple unit operation. The main 3,000-volt control switches are mounted in steel compartments in the center of each locomotive cab with convenient aisles for inspection and repair. These switches are actuated from the master controller by a 125-volt control circuit furnished by the motor-generator set. One of these sets is located in each half of the locomotive and consists of a double commutator, 3,000-volt d.-c. motor, a small control generator and a double commutator, 250-volt generator which is used for regenerative braking. Two slip rings are also provided on the control generator for supplying an alternating current at low voltage for operation of the headlights. On the end of the motor-generator shaft is a blower which



GE-253-A 1500/3000-VOLT MOTOR

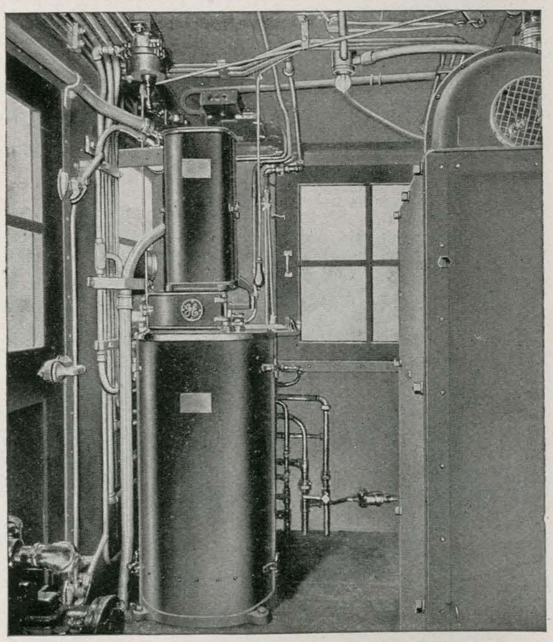
supplies forced ventilation to the four traction motors on each half unit. Current is taken from the trolley wire by a pantograph collector, one of which is mounted on each half of the locomotive.

Pantograph

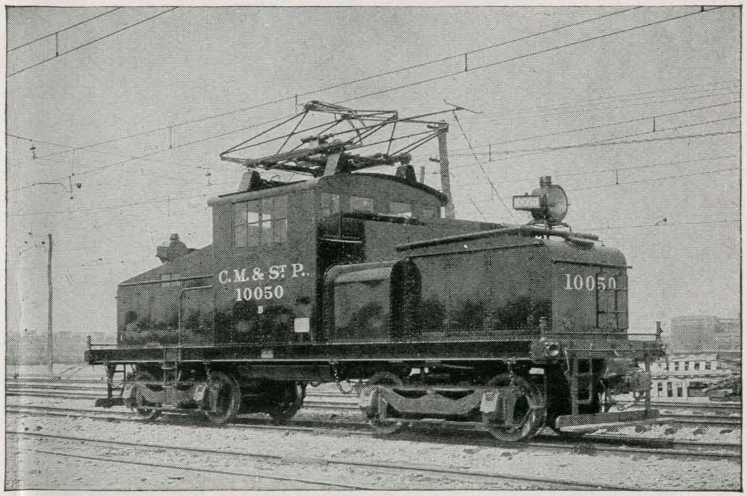
This collector is of the double pan type with a working range of from 17 to 25 feet above the rail. The contact elements are of the same metal as the trolley wire so that current passes from copper to copper. Under normal operation, only one pantograph is used, the second collector being held as a spare. The trolley pan is lubricated in order to reduce wear on the trolley wire.

Air Equipment

The air brake equipment is practically the same as that on steam locomotives except that motor-driven air compressors are used to furnish compressed air. One of these air compressor sets is located in each half unit and has a capacity of 150 cubic feet of free air per minute. Aside from the air brakes, compressed air is also used for signals, whistles, bell ringers, sanders, flange oilers, pantograph, and part of the control equipment.



INTERIOR OF FREIGHT LOCOMOTIVE CAB



3000-VOLT D. C. SWITCHING LOCOMOTIVE

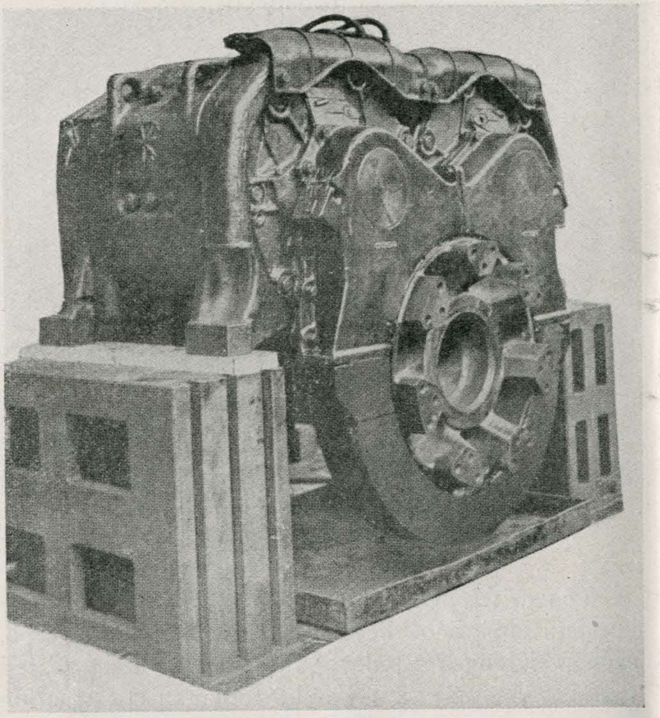
Switching Locomotives

The switching locomotives, four of which are now in operation, are of the swivel-truck, steeple-cab type, each weighing 70 tons equipped with four geared motors. A single pantograph, similar in construction to that used on the main line locomotives, is mounted on the cab and many of the locomotive parts are interchangeable with those of the main line locomotives notably the air compressors, small switches, headlights, and cab heaters. The motors are the GE-255, box frame, commutating pole type designed for 1,500 volts with an insulation of 3,000 volts to permit of operating, two in series.

High-Speed Passenger Locomotives

For passenger service on the Cascade district, a gearless locomotive is used embracing the principal features of the New York Central gearless engines. These locomotives are equipped with twelve driving axles and a guiding axle at each end. The armature is mounted directly upon each axle and the fields are carried upon the truck springs so that there is full freedom for vertical play of the armature between them. The locomotives are guaranteed to haul a twelve-car train weighing 960 tons up a two per cent grade at a speed of 25 m.p.h. The total weight of the locomotive is 521,200 pounds with 457,800 pounds on the driving axles.

It is equipped with twelve GE-100 1,000-volt motors, insulated, as in the case of the freight motors, for 3,000 volts to ground. Each locomotive has a



MAIN MOTOR FOR QUILL SPRING DRIVE PASSENGER LOCOMOTIVE
Assembled complete with quill and gear covers

one-hour rating of 3,500 h.p. and a continuous rating of 3,200 h.p.

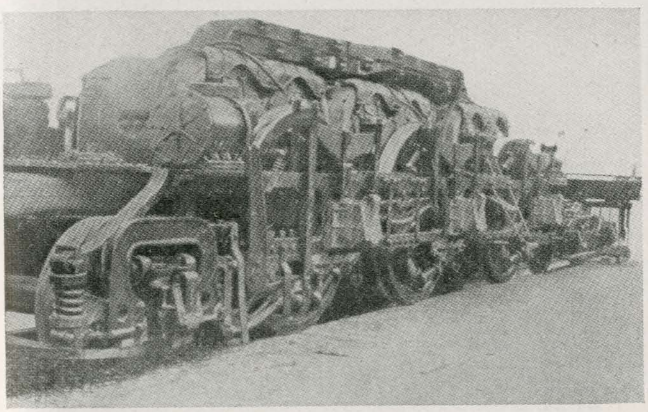
The control equipment is in most respects similar to that used on the freight locomotives except that the motor-generator set for regeneration is eliminated, and four of the traction motors are utilized to furnish the necessary excitation while regenerating on the down grades. A storage battery is also provided for furnishing lights and auxiliary circuits. The arrangement of the control provides for three running speeds: One-fourth, one-half, and full speeds with shunt field notches for obtaining higher speeds when grade and other conditions will permit. The cab arrangement is somewhat novel, the operator's position being near the center of the locomotive and the control apparatus located under a rounded hood at each end. A center cab is provided between the two operating positions in which the train heating apparatus is located. Double-pan type collectors, similar to those used on the original units, are installed over each of the operating cabs.

For passenger service on the Rocky Mountain and Missoula divisions a "quill-type" locomotive is used,

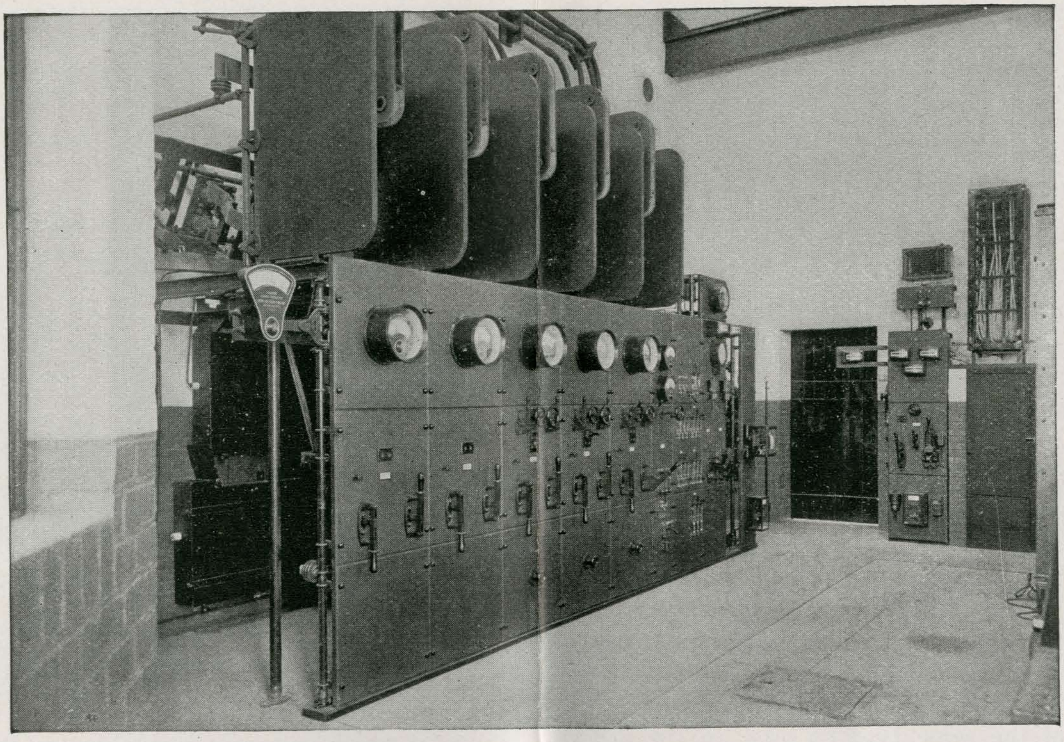
embracing some of the principal features of the New York, New Haven and Hartford locomotives. The quill consists of a hollow shaft which surrounds the driving axle and passes through bearings mounted in the frame of the motor, which is above the quill. The driving torque is transmitted from the quill to the driving wheel by means of concentrically arranged springs attached to the quill and bearing against the driver spokes, the quill itself being geared by single gearing to the two armatures of the motor. The total weight of the locomotive is 566,800 pounds of which 367,600 pounds are on the driving axles.

These locomotives are equipped with six Westinghouse No. 348 twin motors, each of the two armatures being wound for 750 volts and insulated for 3,000 volts to ground. Each locomotive has a one-hour rating of 4,200 h.p. and a continuous rating of 3,400 h.p., and is designed to handle a trailing train weight of 960 tons, as in the case of the gearless motors.

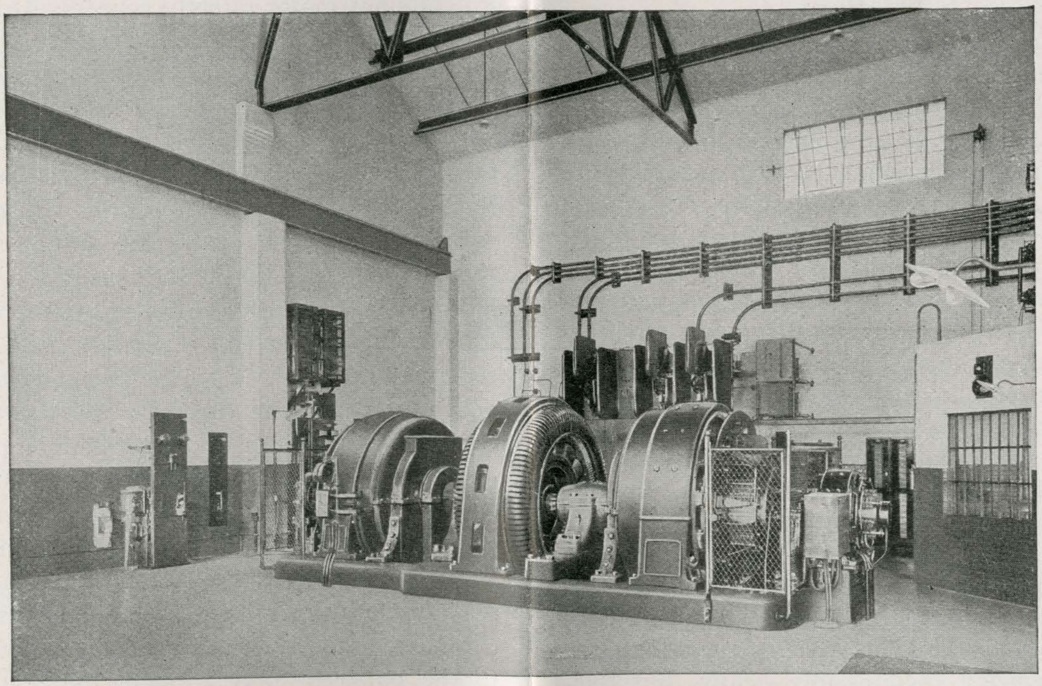
Line current switches are of the electro-pneumatic type, actuated from the main controller by an 85-volt control circuit furnished by a motor-generator set, which, also, in conjunction with axle-generators mounted on the leading trucks and a storage battery, furnishes current for operating the auxiliaries, such as air compressor and train lighting. During regeneration, the axle generators furnish current for exciting the main motor fields. The arrangements of the control provide for three running speeds—one-third, two-thirds, and full speeds—with shunt field notches for obtaining higher speeds when grade and other conditions will permit.



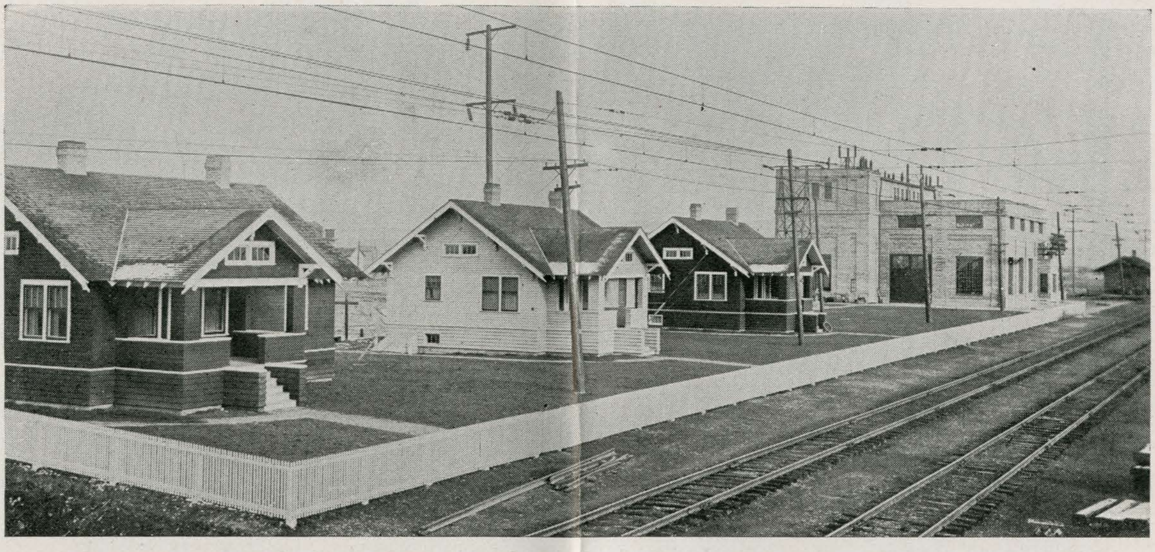
THREE TWIN MOTORS ASSEMBLED ON TRUCK



3000-VOLT DIRECT-CURRENT SWITCHBOARD—PIEDMONT SUBSTATION



2000-KW. 3000-VOLT DIRECT-CURRENT SYNCHRONOUS MOTOR-GENERATOR SET—CLE ELUM SUBSTATION



VIEW OF KITTITAS SUBSTATION, TROLLEY CONSTRUCTION, TRANSMISSION LINE AND COMPANY RESIDENCES

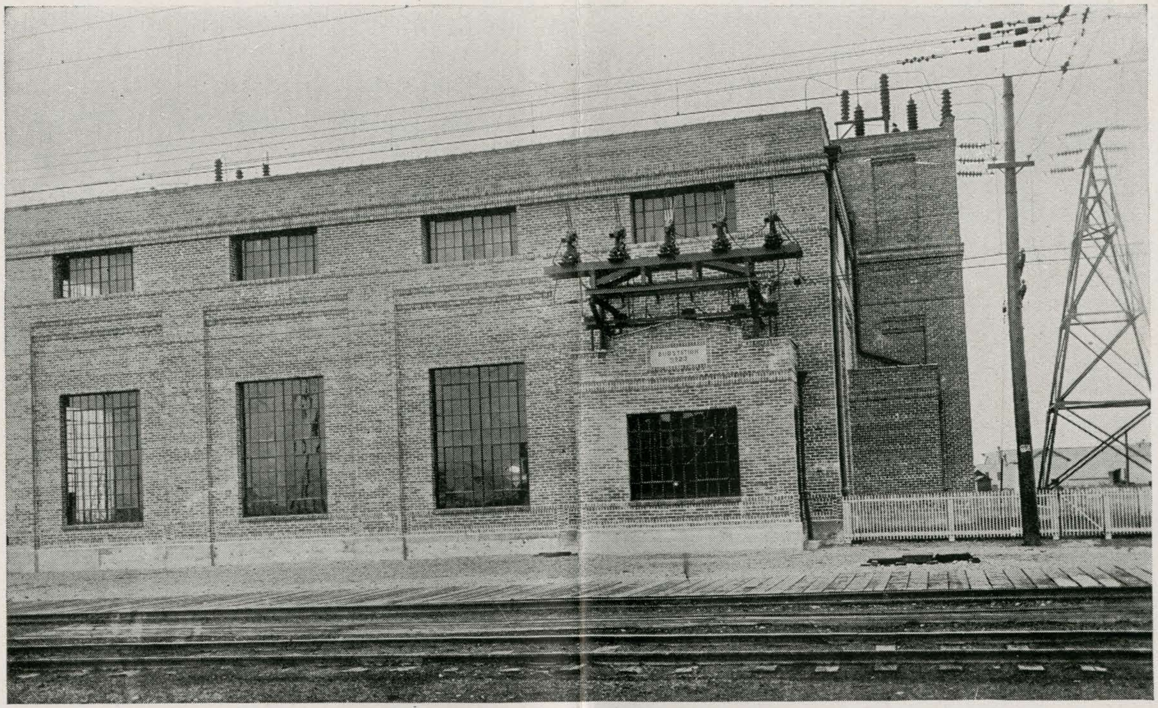
Engineers' operating compartments are located at the two ends of the locomotive and the train heating boiler at the middle. The current collecting pantographs are of the same type as used on the other locomotives.

Substations

The 3,000-volt direct current used by the locomotives is supplied to the trolley system from substations which are connected together by the Railway Company's 100,000-volt transmission line, of which the substation high-tension bus forms a part. Into this bus, at various points, is tapped the transmission system of the Power Companies supplying the power for the operation of the railway. There are fourteen of these substations on the Rocky Mountain and Missoula divisions and eight on the Coast Division. The capacities of the various substations are shown in the tabulation following.

All substations are of the indoor type of brick fire-proof construction and consist of two rooms, one containing the 100,000-volt oil switches, lighting arresters, transformers, and similar high-tension apparatus, and the other containing the motor generators, low-tension switches, and 3,000-volt and auxiliary switchboard. The construction of all substations, except as to size, is the same, except that in locations where the snowfall is unusually heavy, hip roof, instead of flat roof construction is used.

Each motor-generator is fed from the 100,000-volt bus through an individual transformer, which is of the 3-phase type and transforms to current of 2,300 volts, at which voltage it is received by the motor of the motor-generator set. The latter consists of a synchronous motor directly connected to two 1,500-volt direct-current generators permanently connected in series to give the 3,000-volt trolley current. The over-load capacities of these motor-generators are very high, they being guaranteed to carry a 50 per cent over-load for two hours, or a 300 per cent load for five minutes. Special ventilating arrangements are provided, which, in the case of the substations of the Missoula and Coast divisions, comprise separate blowers automatically controlled by thermostat. The exciters for motors and generators, respectively, are separate and mounted on the two ends of the motor-generator shaft, the exciter of the motor being so compounded as to maintain in the motor supply circuit a current of unity or leading power factor for all loads above half load. When the current at a substation reverses, due to regeneration by a locomotive going down grade, the direct-current generators of a set automatically become motors and drive the synchronous motor as a generator, thus becoming known to the onlooker only through the reversal of the various meters.



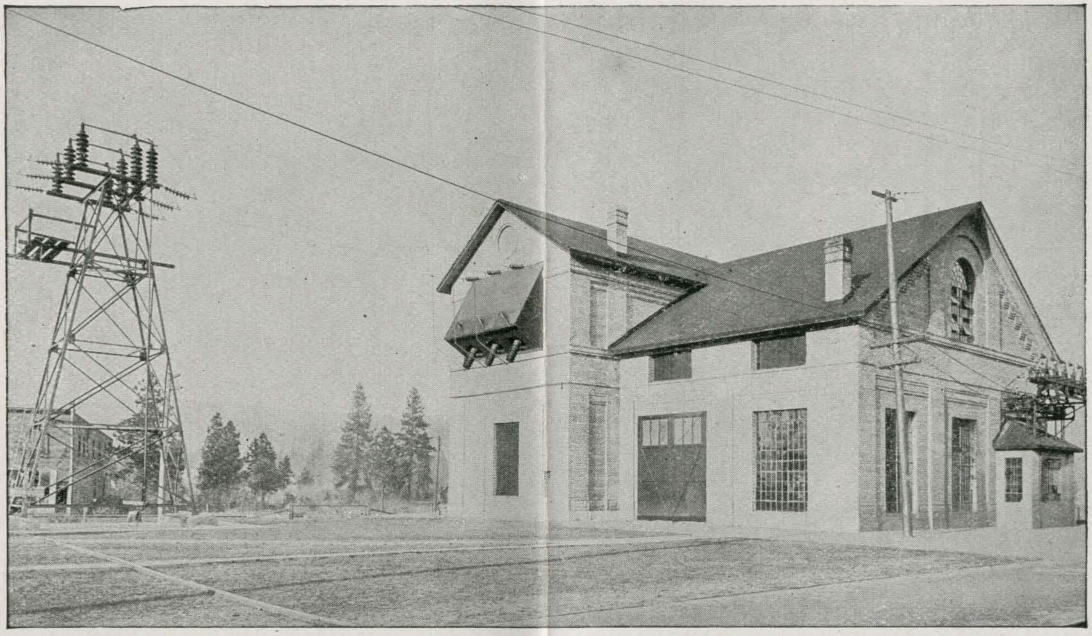
KITTITAS SUBSTATION

Location and Equipment of Substations

Substation Number	Location	Number	Size of Units in Kilowatts	Installed Cap. Kw.	Substation Capacity in Kw.
1	Two Dot, Mont...	2	2,000	4,000	4,000
2	Summit, Mont....	2	2,000	4,000	4,000
3	Josephine, Mont...	2	2,000	4,000	4,000
4	Eustis, Mont......	2	2,000	4,000	4,000
5	Piedmont, Mont...	3	1,500	4,500	4,500
6	Janney, Mont.....	3	1,500	4,500	4,500
7	Morel, Mont......	2	2,000	4,000	4,000
8	Gold Creek, Mont.	2	2,000	4,000	4,000
9	Ravenna, Mont...	2	2,000	4,000	4,000
10	Primrose, Mont...	2	2,000	4,000	4,000
11	Tarkio, Mont.....	2	2,000	4,000	4,000
12	Drexel, Mont.....	2	2,000	4,000	4,000
13	East Portal, Mont.	3	2,000	6,000	6,000
14	Avery, Idaho.....	3	1,500	4,500	4,500
Totals (R.M.& Mala. Div.)		32		59,500	59,500
21	Taunton..........	2	2,000	4,000	4,000
22	Doris............	2	2,000	4,000	6,000
23	Kittitas..........	2	2,000	4,000	6,000
24	Cle Elum.........	1	2,000	2,000	4,000
25	Hyak............	2	2,000	4,000	6,000
26	Cedar Falls.......	2	2,000	4,000	6,000
27	Renton...........	1	2,000	2,000	4,000
28	Tacoma..........	2	2,000	4,000	4,000
Totals (Coast Division)..		14		28,000	40,000
GRAND TOTAL...........		46		87,500	99,500

Flash-Over Protection

Perhaps one of the most interesting features in connection with the direct-current switching installation in the substations is the arrangements which have been provided to prevent so-called flash-over of the generators in case of short circuit on trolley line. In the earlier substations, those of the Rocky Mountain and Missoula divisions, this device consisted of a so-called "high-speed circuit breaker," which is connected in the negative lead to the tracks. In case of a short circuit on the trolley system or over-load on the substations, this circuit breaker opens and introduces a resistance into the direct-current trolley circuit before the current rises to a sufficient value to cause flash-over of the generators, the current being thus reduced to a current readily handled by the regular switchboard breakers. The use of this apparatus does away with the necessity of employing the comparatively ineffective and wasteful method of connecting the substation bus to the trolley system through permanent ohmic resistance. The operation of this breaker was very successful, but by the time specifications were drawn up for apparatus for the substations of the Coast Division, still more improved



CLE ELUM SUBSTATION

apparatus had been developed for the prevention of flash-overs. In five of the substations this apparatus consists of a high-speed circuit breaker, which, instead of being connected into the main negative lead from the substation, is connected into the negative of the individual motor generators, one breaker being supplied for each motor generator. This breaker operates on an entirely different principle from the original breaker as regards method of tripping and arrangement of blowout, these improvements allowing a reduction in size, weight, and cost. The new breaker is tripped electro-magnetically instead of mechanically, and the size of spring necessary to operate the device is, therefore, comparatively small. A similar circuit breaker also comprises part of the equipment of each of the gearless locomotives.

In three of the substations on the Coast Division, a so-called "flash-suppressor" is used to prevent flash-overs. This protection consists of equipping the direct-current generators with 3-phase collector rings and providing switching apparatus constituting the so-called "flash suppressor," which, in case of short circuit or flow of predetermined current, short circuits the collector rings and establishes current in the armature windings, which causes the voltage of the generator to drop and, thereby, correspondingly lower the

flow of current, relieving the commutators and brushes of the heavy currents which they would otherwise carry. The motor generators, which are provided with these flash-suppressors, will, of themselves, carry without flash-over a current eleven times the normal rated current of the machine.

Relay Protection

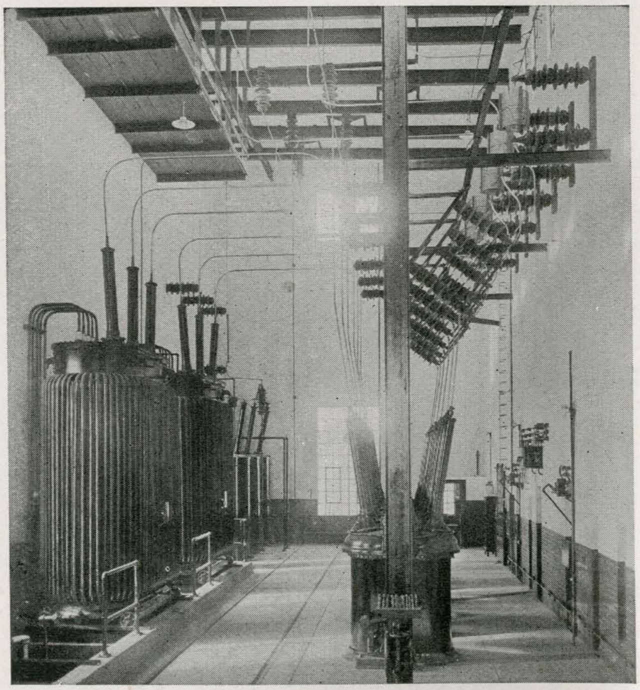
Another important feature of the substations and one which has been very satisfactorily developed on this installation is that of the relay protection in the Railway and Power Company's transmission lines. The function of these relays is, in case trouble develops on any portion of the transmission system due to failure of insulators, falling of trees across the line, or other causes, to select and automatically cut out of the system the particular portion of the line between two substations which is in trouble, so that the operation of the remainder of the line continues uninterrupted.

Special Features

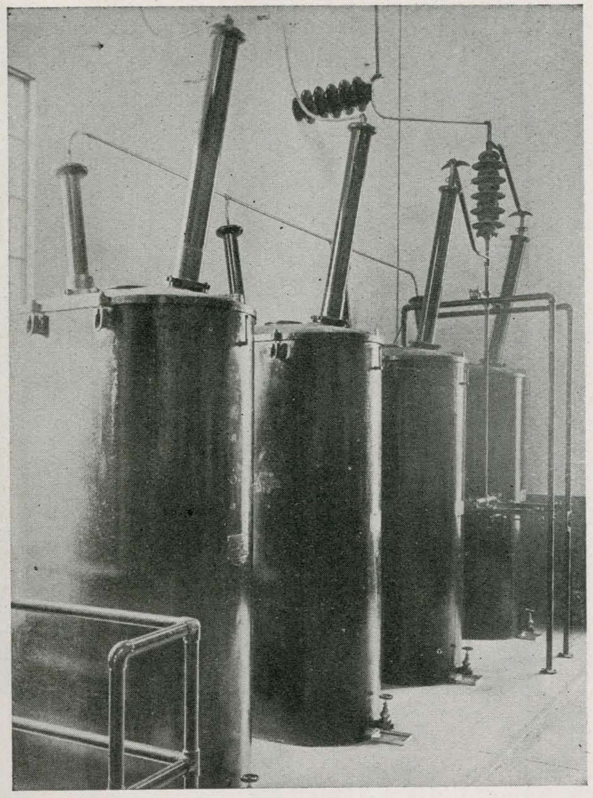
Another feature of interest which exists in the substations on the Coast Division and which constitutes improvements in substation design is the location of the low-tension oil switches for synchronous motor control and other purposes in the basement below the motor-generator room instead of in the motor-generator room itself, this feature providing increased space in the motor-generator room, and additional safety to operator or to surrounding apparatus in case trouble develops in a switch. Also in these substations there are provided so-called air break disconnecting switches, which are installed in the 3,000-volt feeder connections running out from the substation and connecting with the trolley and the adjacent substations. These switches are mounted on the outside of the building above the substation office and operated from within the latter. These switches are adapted to open 7,000 or 8,000 amperes at 3,000 volts, and in case of any trouble on the wiring within the stations, enable the supply of current from the adjacent substations to be entirely cut off from within the building.

Attendants' Dwellings

At each station there are provided dwellings for the operators. These buildings are of pleasing design of the bungalow type and are provided with electric light and high-pressure water, an automatic pumping plant being installed for furnishing the latter.



HIGH-TENSION ROOM

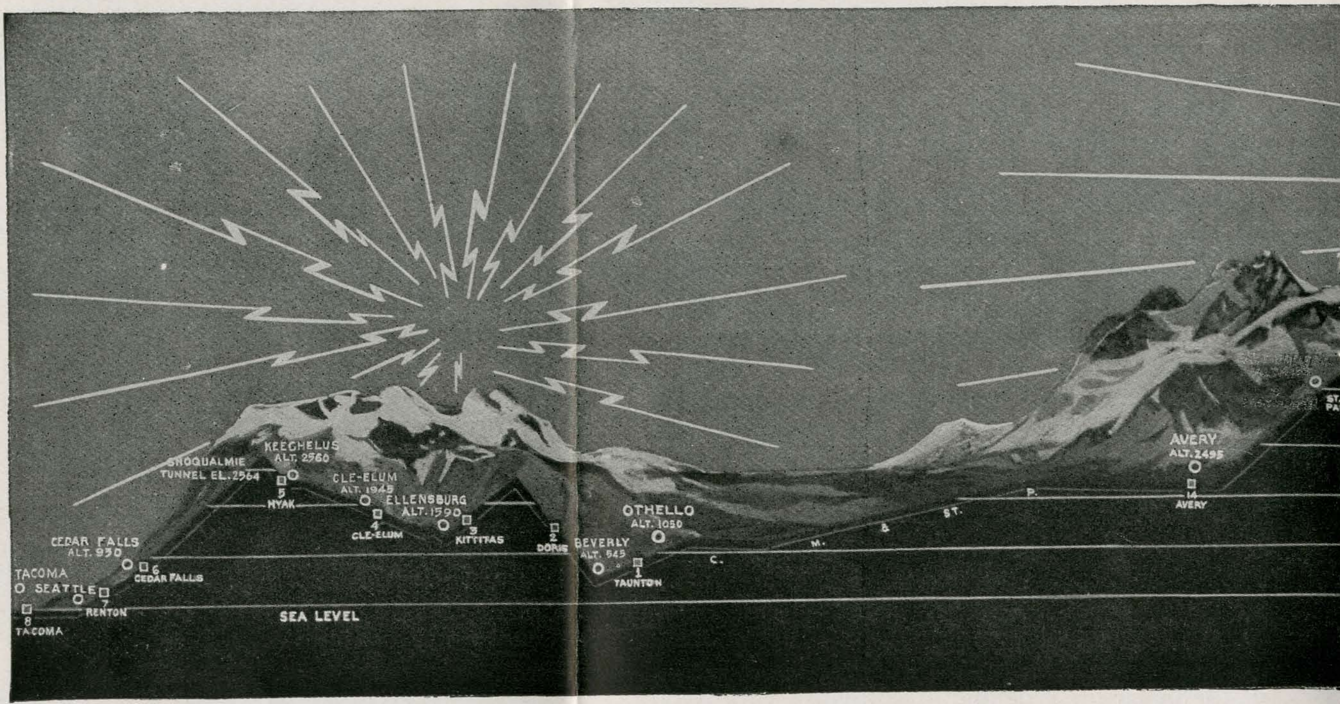


115000-VOLT LIGHTNING ARRESTERS

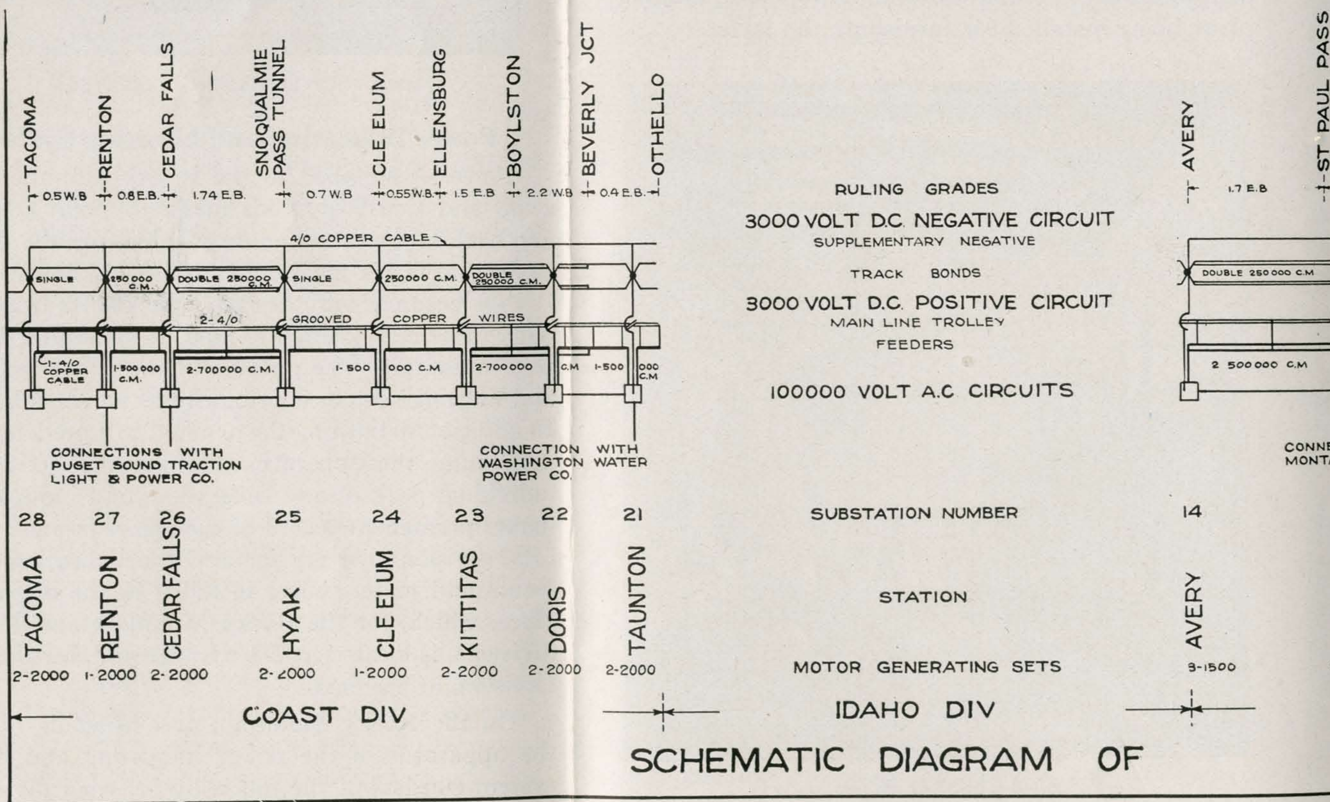
Power Indicating and Limiting System

Power is supplied to the Rocky Mountain, Missoula and Coast divisions under different contracts, and each involves minimum payment on the demand basis, that is, the maximum number of kilowatts used. It thus becomes very desirable for the Railway Company to be in a position to hold its maximum demand to a minimum. The purpose of the power indicating and limiting system is primarily to secure this result. In addition to limiting the demand to a predetermined maximum, the apparatus also permits limiting the individual peak of any substation, and indicates and makes permanent record of the use of power over the total division at every instant, the indicating instruments and meters being installed in the dispatcher's office, which, for the Rocky Mountain and Missoula divisions, is located at Deer Lodge and, for the Coast Division, at Tacoma.

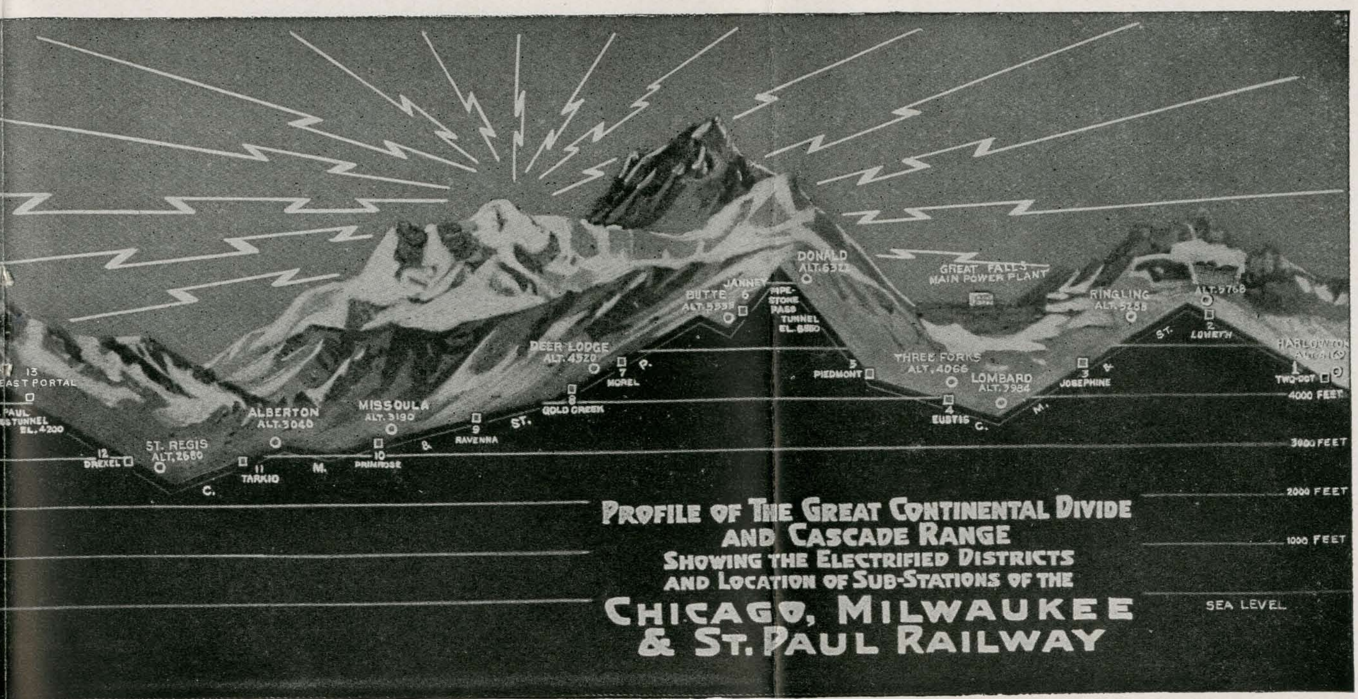
On the Rocky Mountain and Missoula divisions the apparatus of the power indicating and limiting system consists of the following for each division:

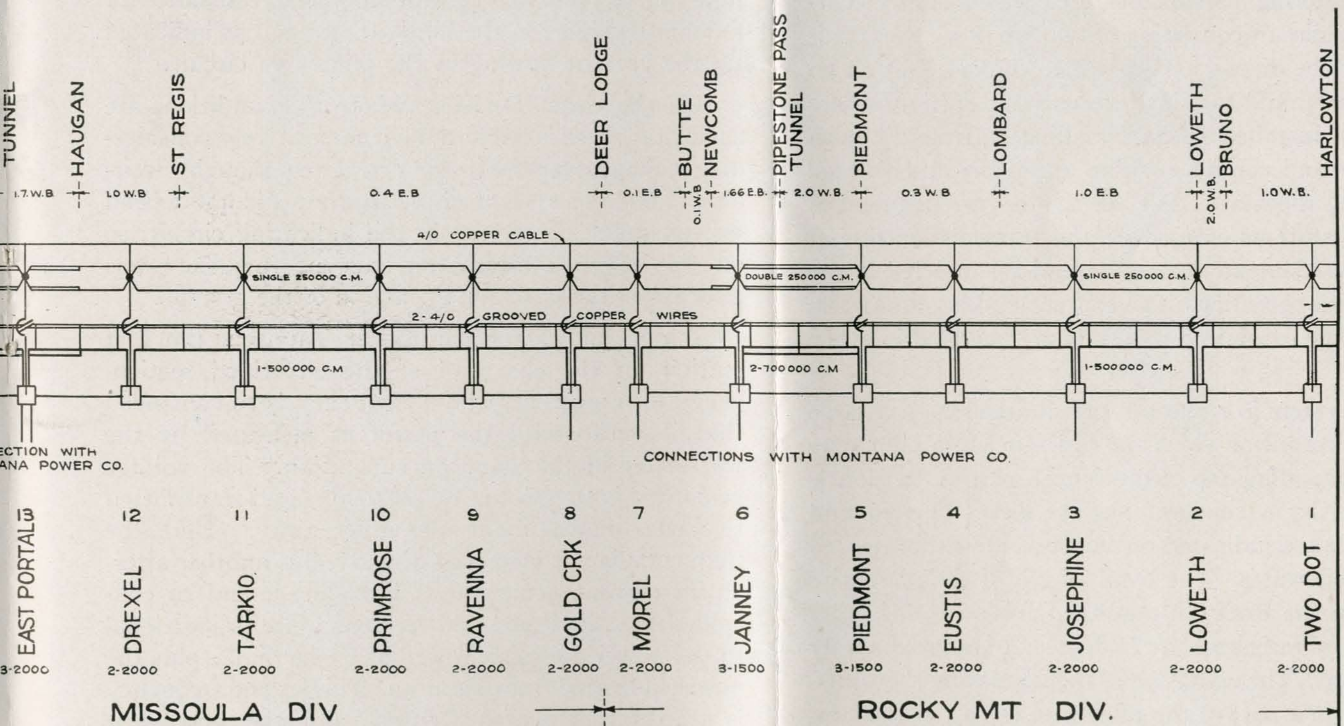


SNOQUALMIE TUNNEL EL. 2564
KEECHELUS ALT. 2560
CLE-ELUM ALT. 1945
ELLENSBURG ALT. 1590
OTHELLO ALT. 1050
BEVERLY ALT. 545
AVERY ALT. 2495
CEDAR FALLS ALT. 930
TACOMA
SEATTLE
5 HYAK
4 CLE-ELUM
3 KITTITAS
2 DORIS
1 TAUNTON
6 CEDAR FALLS
7 RENTON
8 TACOMA
14 AVERY
C. M. & ST. P.
SEA LEVEL

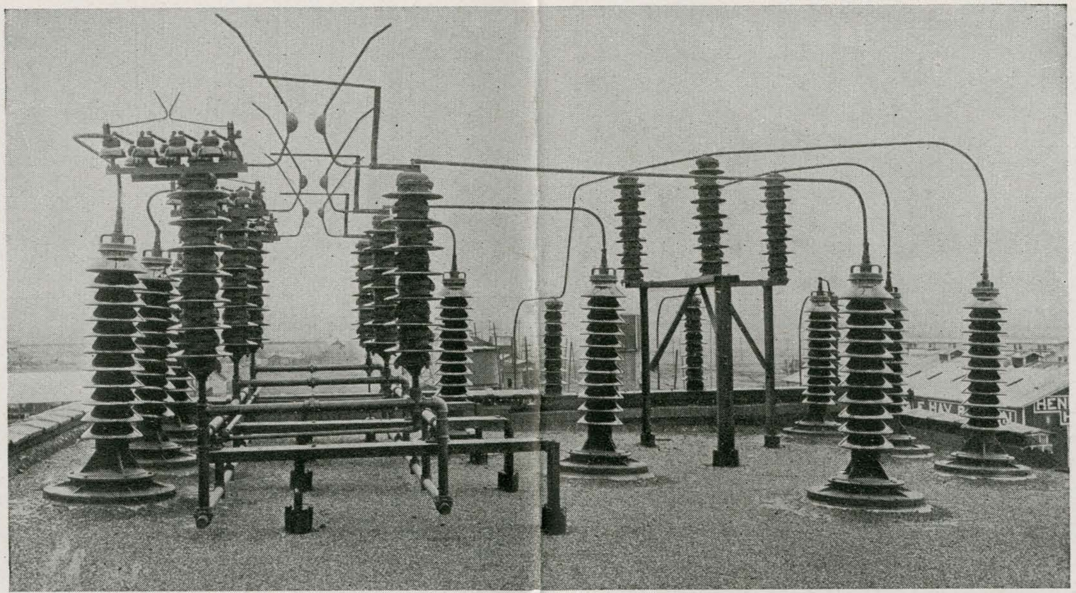


TACOMA
RENTON
CEDAR FALLS
SNOQUALMIE PASS TUNNEL
CLE ELUM
ELLENSBURG
BOYLSTON
BEVERLY JCT
OTHELLO
AVERY
ST PAUL PASS
0.5 W.B
0.8 E.B.
1.74 E.B.
0.7 W.B
0.55 W.B.
1.5 E.B
2.2 W.B
0.4 E.B.
1.7 E.B
RULING GRADES
3000 VOLT D.C. NEGATIVE CIRCUIT
SUPPLEMENTARY NEGATIVE
TRACK BONDS
3000 VOLT D.C. POSITIVE CIRCUIT
MAIN LINE TROLLEY
FEEDERS
100000 VOLT A.C CIRCUITS
4/0 COPPER CABLE
SINGLE
250 000 C.M.
DOUBLE 250000 C.M.
SINGLE
250000 C.M.
DOUBLE 250000 C.M.
DOUBLE 250 000 C.M
2-4/0
GROOVED COPPER WIRES
1-4/0 COPPER CABLE
1-500 000 C.M.
2-700000 C.M.
1-500
000 C.M
2-700000
C.M
1-500
000 C.M
2 500000 C.M
CONNECTIONS WITH PUGET SOUND TRACTION LIGHT & POWER CO.
CONNECTION WITH WASHINGTON WATER POWER CO.
SUBSTATION NUMBER
28 27 26 25 24 23 22 21
14
STATION
TACOMA
RENTON
CEDAR FALLS
HYAK
CLE ELUM
KITTITAS
DORIS
TAUNTON
AVERY
MOTOR GENERATING SETS
2-2000
1-2000
2-2000
2-2000
1-2000
2-2000
2-2000
2-2000
3-1500
COAST DIV
IDAHO DIV
SCHEMATIC DIAGRAM OF





ELECTRICAL CIRCUITS



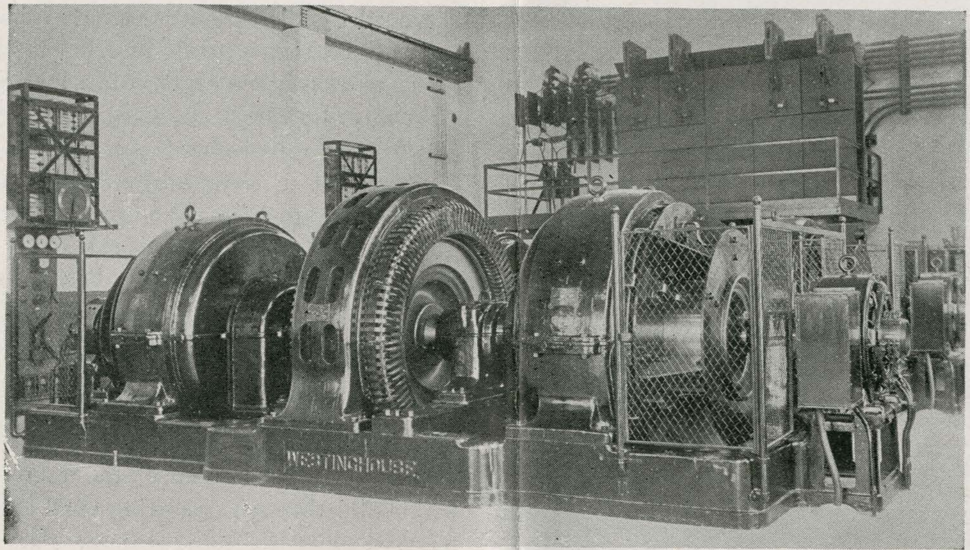
CONDENSER-TYPE ROOF BUSHINGS AND HORN GAPS

A 2-kw., 1,200-volt direct-current motor-generator set in the dispatcher's office with controlling switchboard, metering instruments, etc., which supplies current for a circuit consisting of two No. 8 wires extending from the dispatcher's office to the last station on the division, and tapping into each substation, where there are installed contact-making wattmeters with rheostats and contact-making ammeters and voltage regulating rheostats. The wattmeters are installed in those substations only where the transmission line of the Power Company comes in, and are inserted in the Power Company line. The contact-making ammeters and voltage regulating rheostats are installed in every station.

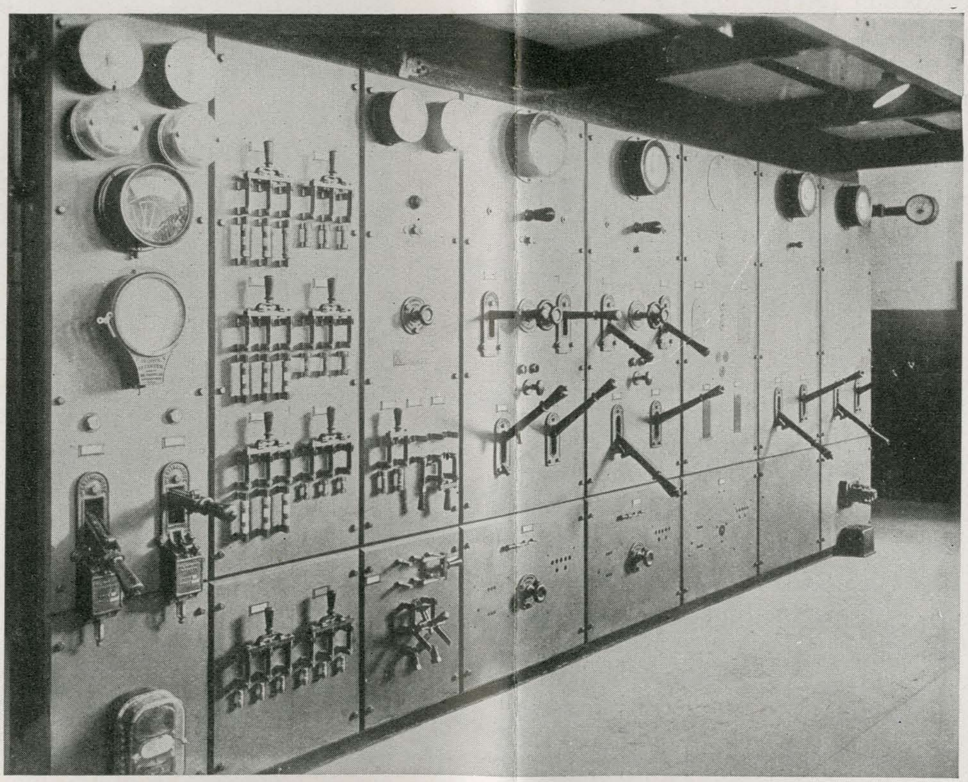
The system is essentially an ohmmeter on a large scale, by means of which the resistance of a pilot wire circuit extending the entire length of the division is measured by a constant voltage direct current and the resistance indicated on instruments calibrated to read in kilowatts. The total length of the pilot wire circuit on the Rocky Mountain Division is 434 miles with a total resistance, at 75 degrees, of approximately 1,450 ohms. The operation of the regulating rheostats, which form a part of the pilot wire circuit in the substations, is effected by contact-making ammeters, which actuate motor-operated rheostats connected into the field circuits of the direct-current generators. The indicating and limiting feature is obtained by inserting or removing certain sections of resistance for a definite change in the kilowatt demand as indicated by the current flowing in the pilot wire circuit.

On the Coast Division, where the conditions are such that there is liable to be comparatively considerable leakage over the insulators, it was thought desirable to install a system whose accuracy did not depend on constancy of current in the indicating circuit, so on this division alternating current frequency was selected as the basis for the action of the system.

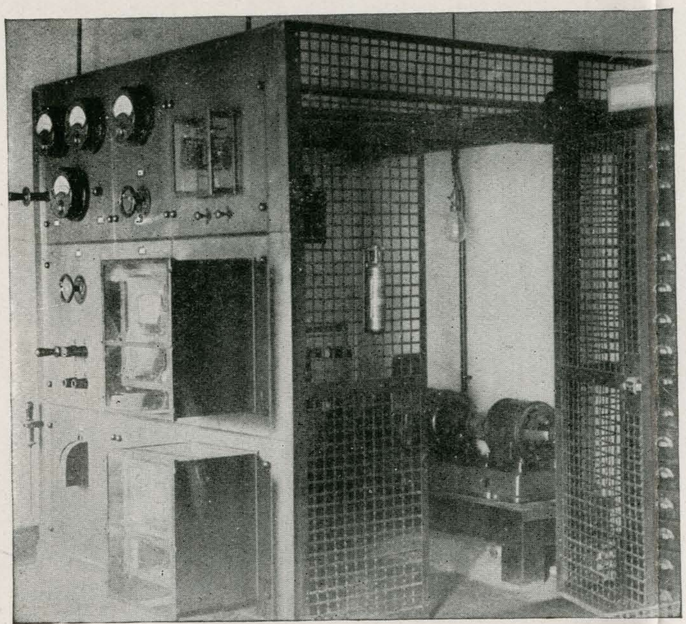
A one kilowatt generator at Taunton, the first station on the east end of the electrified section, generates a current, whose frequency is so controlled that it varies with the power as measured by the wattmeter in the Taunton substation. The voltage generated is stepped up to 2,000 volts and transmitted to Cedar Falls, about 100 miles away. Here the frequency is not increased directly, but another alternating-current generator is introduced, and so controlled that its speed and frequency are proportional to the power being measured at Cedar Falls, plus the power indicated from Taunton. This second frequency is transmitted on to Renton, and the process is repeated. From Renton, the frequency goes to the dispatcher's office near Tacoma, where it indicates



MOTOR-GENERATOR SET, KITTITAS SUBSTATION



MAIN DIRECT-CURRENT SWITCHBOARD



POWER LIMITING AND INDICATING EQUIPMENT IN DISPATCHER'S OFFICE AT DEER LODGE

the total of all the power received by this electrified section of railroad.

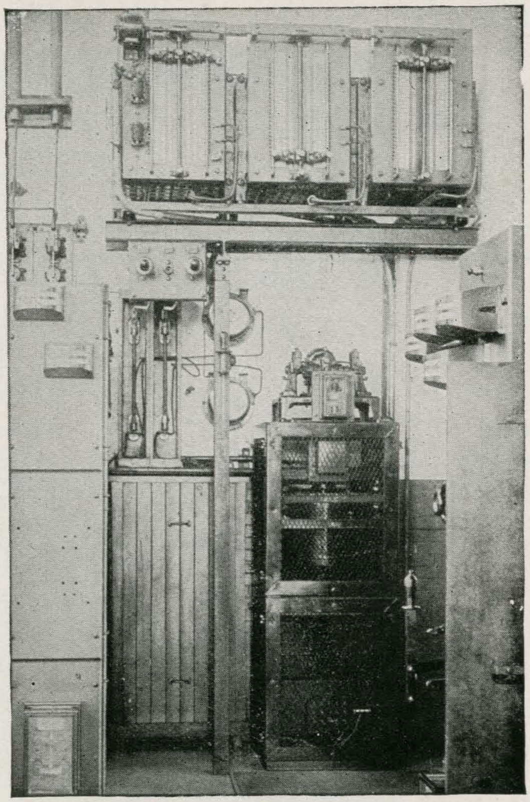
The limiting of the demand is accomplished through the agency of the load regulator. When the load approaches a predetermined point, this regulator closes its contacts in the lowering direction and sends out over the signaling circuit a direct current which operates a polarized relay in each substation. The signaling circuit consists of the same wires that carry the frequency indications. The direct current is fed into the middle of the high-tension winding of the transformers, and as it divides equally in the two halves of the winding, it has no effect on the magnetic circuit. The two wires in parallel thus form a "phantom" or derived circuit, the return circuit being through the ground from Taunton back to the load dispatcher's office.

The generator field circuits in each substation are provided with a motor-operated rheostat, in addition to the usual field rheostat, whose function is solely to reduce the voltage of the generators, which supply power to the 3,000 volt trolley, at times of heavy overload. These rheostats are controlled by inverse time element overload relays, which are normally set to reduce the voltage at 300 per cent of rated load. The operation of the polarized relays when they are

actuated by the current from the phantom circuit is to cause resistance to be inserted in the fields of the direct-current generators, thus lowering the direct-current voltage as in the case of the Rocky Mountain and Missoula divisions.

The direct-current voltage, which has been lowered as necessary to hold the power demand down to the predetermined limit, is automatically raised again as the load conditions gradually become such that limiting action is no longer required.

With the power indicating and limiting system the Railway has been able to maintain very high load factors for this class of service with corresponding saving in cost of power. With too great limiting action there is, of course, too much slowing up of trains and through operating experience the Railway has arrived at the most suitable load factor at which to run, considering both cost of power and effect on train movement. This desired load factor, with normal business, is about 53 per cent.

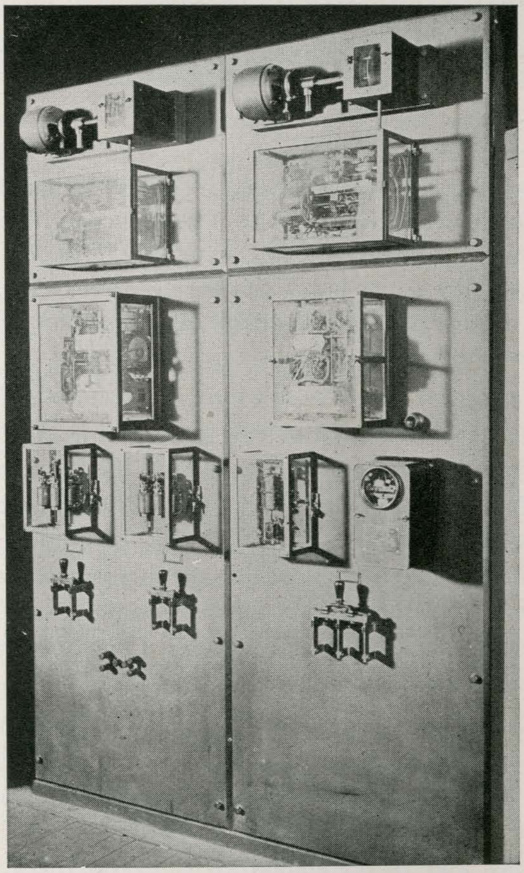


POWER LIMITING AND INDICATING EQUIPMENT INSTALLED IN SUBSTATION

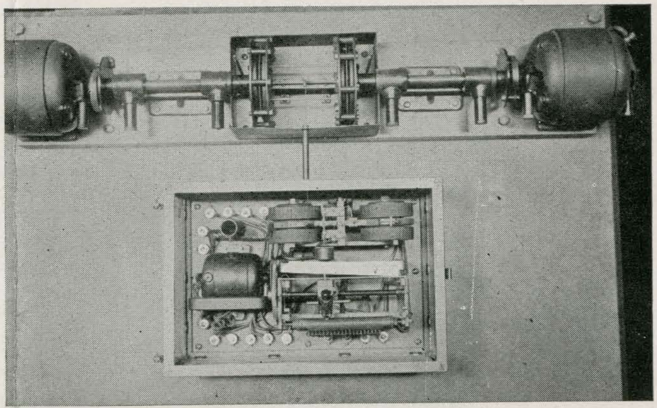
Power Supply

The power for the Rocky Mountain and Missoula divisions is furnished by the Montana Power Co. A list of the plants, with their location and installed capacity, is shown in a tabulation following. These plants are all connected together by a net work of transmission lines, operated mostly at 100,000 volts and over 1,000 miles in length. This net work, for the Rocky Mountain Division, is connected to the transmission system of the Railway Company at five of the seven substations, namely: Two Dot, Josephine, Piedmont, Janney and Morel.

On the Missoula Division there are two points of connection, namely, the Gold Creek and East Portal substations. These power taps are all connected together by the Railway Company transmission line, which extends over each division between the first

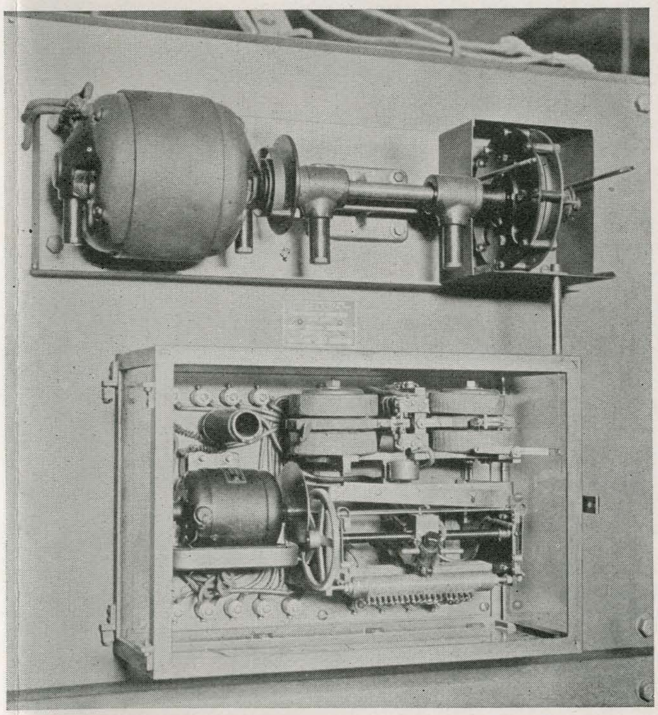


POWER INDICATING AND LIMITING BOARD AT THE DISPATCHER'S STATION, TACOMA



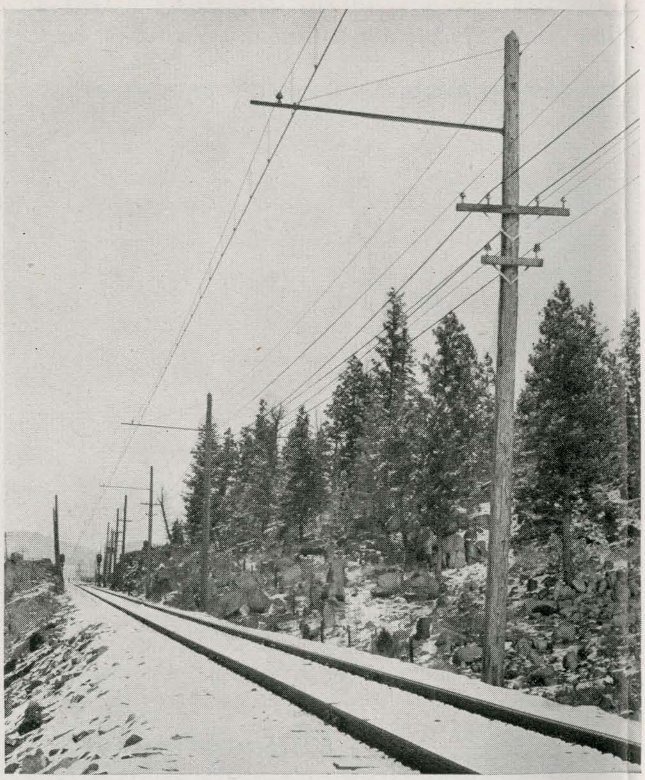
EQUALIZING WATTMETER AND SYNCHRONOUS MOTORS AT AN INTERMEDIATE STATION

and last substations. The transmission line is provided, at substations, with switch operating relays, which, in case of trouble on any portion of the transmission line, automatically isolate such portion from the rest of the line. There is thus no interruption of power at stations where the automatic switches have been provided, and the other stations, located between automatic stations, are interrupted for a very short time only, until non-automatic switches may be



EQUALIZING METER AT TAUNTON

WASHINGTON WATER POWER DEVELOPMENT AT LITTLE FALLS, SPOKANE, WASH.

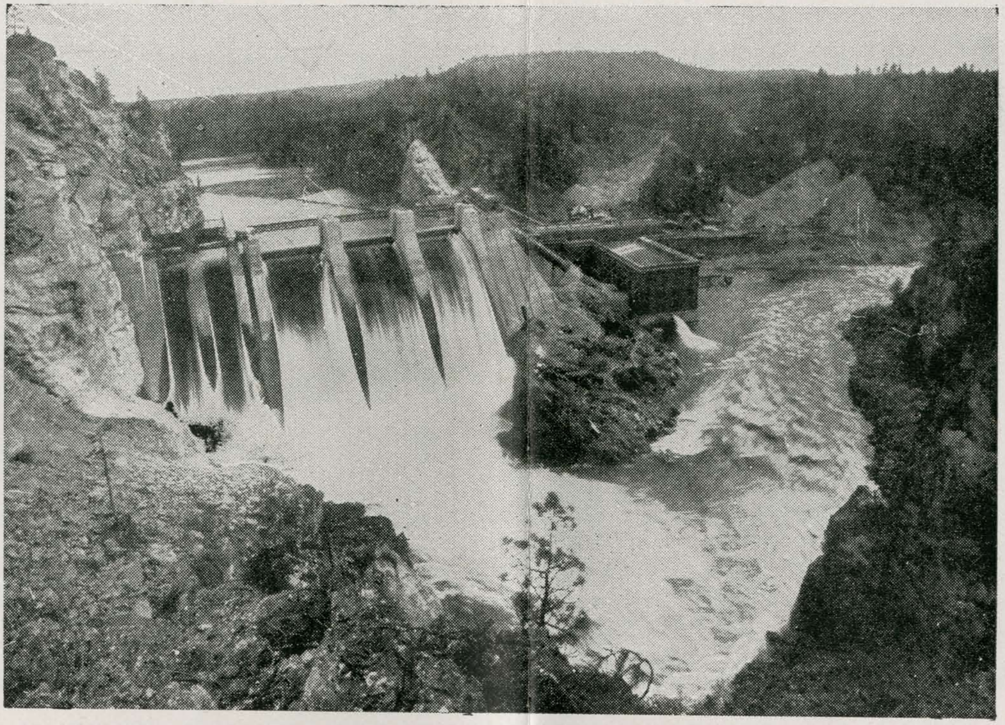


TANGENT BRACKET TROLLEY CONSTRUCTION

opened and the defective portion of the line disconnected. Each substation thus has two and in some cases three different sources of power supply, and the service is very reliable. The system of the Montana Power Co. is one of the most extensive in the country and supplies many industries besides that of the railway, a large part of this power being used for mining and smelting operations.

Power for the Coast Division is supplied over the transmission lines of the Inter-Mountain Power Company, from the power systems of the Washington Water Power Co., and the Puget Sound Traction, Light and Power Co., the location of whose more important plants, with their respective kilowatt capacities, is also shown in a following tabulation. This power is supplied to the Railway Company at the Taunton, Cedar Falls, and Renton substations.

The Railway Company's transmission line extends from the Taunton to the Cedar Falls substation and from the Renton to the Tacoma Junction substation. These substations are provided with automatic oil switches and relays similar to those on the Rocky Mountain and Missoula divisions.



LONG LAKE PLANT OF THE WASHINGTON WATER POWER COMPANY
HAVING A TOTAL CAPACITY OF 65,000 HP.

Electric Plants of the Montana Power Co.

Completed Hydroelectric Plants

Completed Hydroelectric Plants	Installed Capacity Kilowatts
Great Falls, on Missouri River	60,000
Rainbow Falls, on Missouri River near Great Falls, completed in 1910	35,000
Black Eagle Falls, on Missouri River near Great Falls, reconstructed in 1913	3,000
Hauser Lake, on Missouri River, northeast of Helena, completed in 1911	18,000
Canyon Ferry, on Missouri River, northeast of Helena, completed and enlarged in 1901	7,500
Madison No. 1, on Madison River, 60 miles southeast of Butte, completed in 1901, remodelled in 1907	2,000
Madison No. 2, on Madison River, 60 miles southeast of Butte, completed in 1906	10,000
Big Hole, on Big Hole River, 22 miles southwest of Butte, completed in 1898	3,000
Livingston, on Yellow River, completed in 1906 and enlarged in 1908	1,500
Holter, on Missouri River near Helena, under construction	40,000
Billings No. 1, on Yellowstone River, completed in 1907	1,080
Lewiston, on Spring Creek, completed in 1906 and remodelled in 1913	450
Thompson Falls, on Clark's Fork of Columbia River	30,000
Total	211,530

Steam Plants

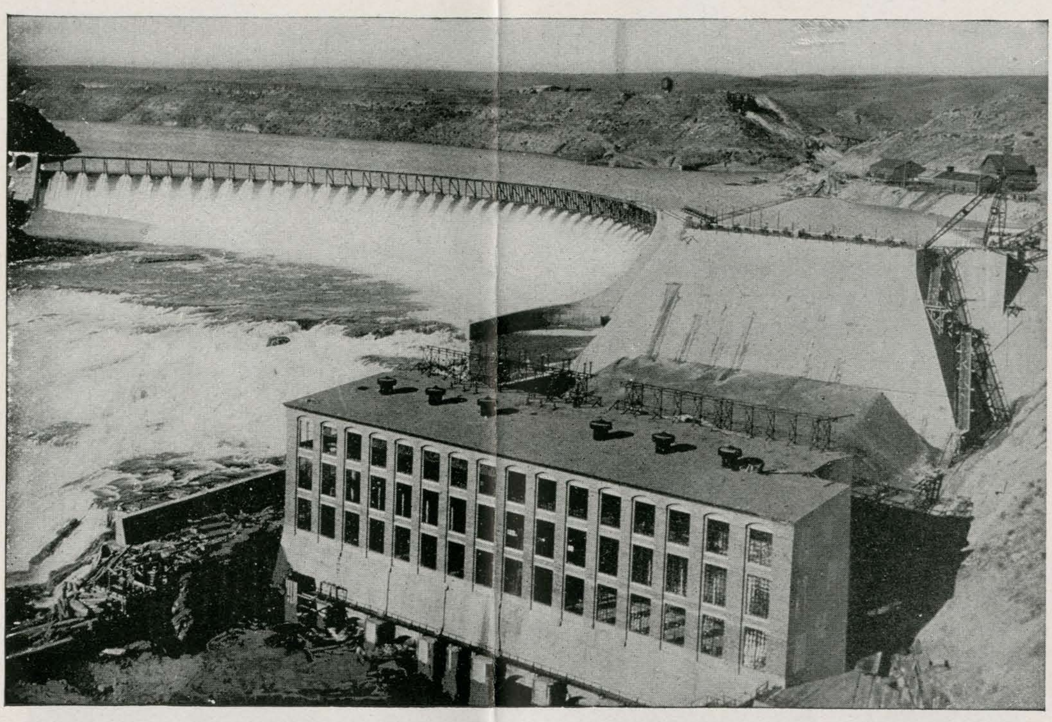
Billings, completed in 1906	560	
Phoenix, in Butte, completed in 1895	250	810
Total		212,340

Hydroelectric Power Sites Undeveloped

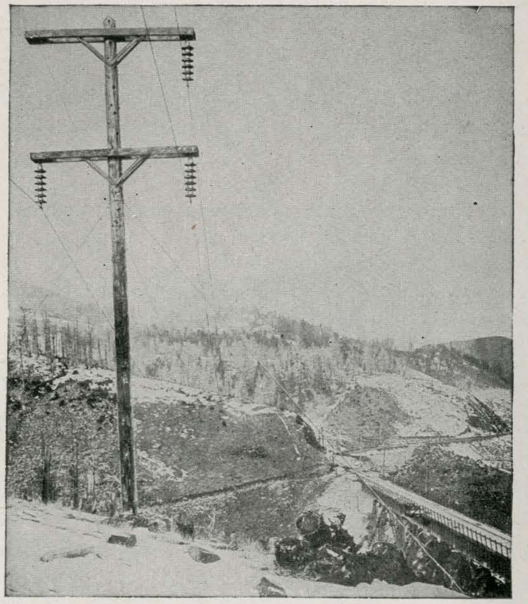
Site "C" at Great Falls, on Missouri River, between Rainbow and Great Falls	28,500
Below Great Falls, on Missouri River (Sheep Creek)	28,500
On Missouri River about 30 miles northwest of Missoula	13,500
Madison No. 3, on Madison River	13,500
Black Eagle Plant, reconstruction	10,000
Snake River Falls, on Henry's Fork of Snake River, 20 miles north of St. Anthony, Idaho	22,500
Mystic Lake on Rosebud River	10,000
Total	131,500

These water power plants are so located at widely separated points that there is little probability of an interruption of the supply.

Available capacity of storage reservoirs in service is 447,150 acre feet, of which the largest, the Hebgen reservoir on Madison River, contributes 325,000 acre feet. There is a further undeveloped capacity of 78,500 acre feet.



HYDROELECTRIC DEVELOPMENT OF THE MONTANA POWER COMPANY AT GREAT FALLS ON THE MISSOURI RIVER



100,000-VOLT RAILWAY COMPANY TRANSMISSION LINE

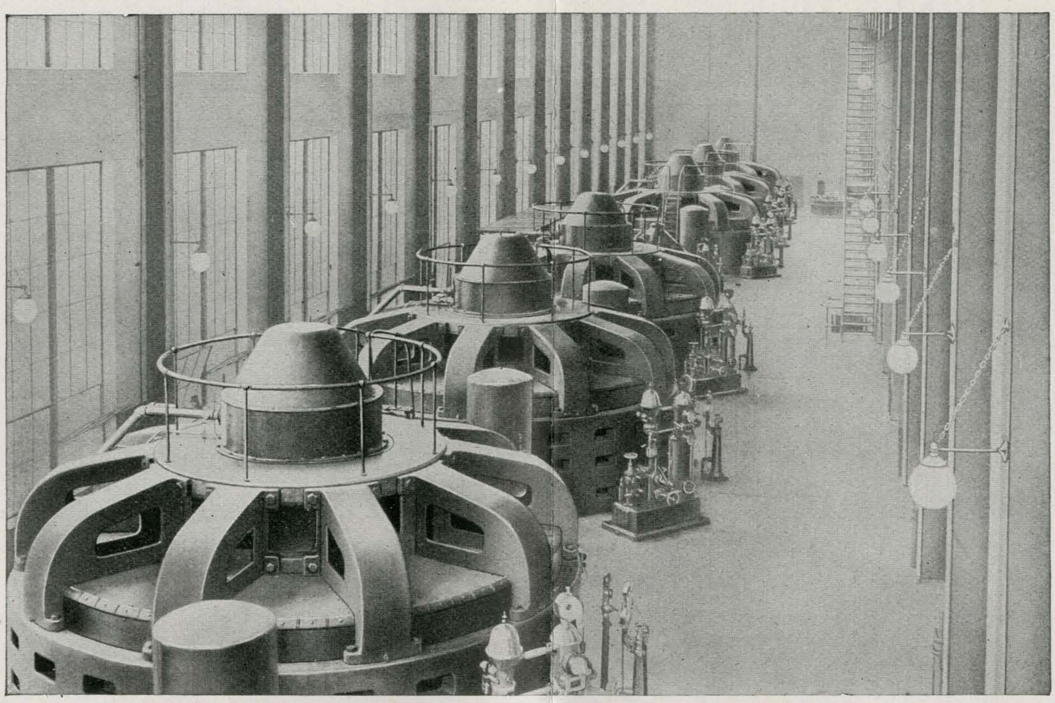
Power for the operation of the Coast and Columbia divisions is supplied by the Inter-Mountain Power Company which, in turn, purchases energy from the Washington Water Power Company and the Puget Sound Traction, Light and Power Company. The generating stations operated by these two companies are mainly hydroelectric, and their capacity is as follows:

Hydroelectric Plants of Puget Sound Traction, Light and Power Co.

	Kilowatts
Snoqualmie Falls No. 1 and 2 (1898–1910)	19,750
White River (1911)	46,000
Electron (1903)	14,000
Total	79,750

Washington Water Power Co.

Spokane, Spokane River	8,800
Post Falls, Spokane River	11,250
Little Falls, Spokane River (1910)	23,000
Long Lake on Long Lake (1915)	46,500
Total	89,550



INTERIOR OF GREAT FALLS POWER STATION SHOWING SIX 10,000-KV-A., 6600-VOLT GENERATORS

Data on Principal Transmission Lines Above 50,000 Volts

Montana Power Co.—100,000-Volt Lines

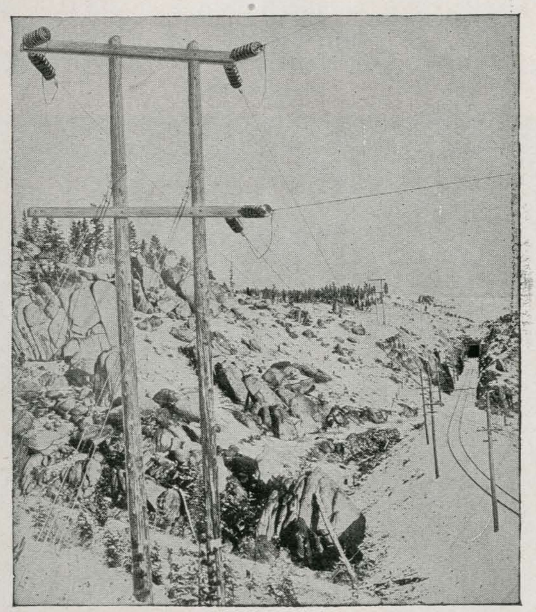
	Miles
Great Falls to Morel and Anaconda	143
Branch to Gold Creek	15
Great Falls to Two Dot and Harlowton	114
Rainbow to Butte via East Helena	125
East Helena to Josephine	55
Madison No. 1 and No. 2 to Butee	62
Thompson Falls to East Portal and Coeur d'Alene	23
Other 100,000-volt branches, etc	62
65,000-volt lines	120
50,000-volt lines	629

Inter-Mountain Power Co.—100,000-Volt Lines

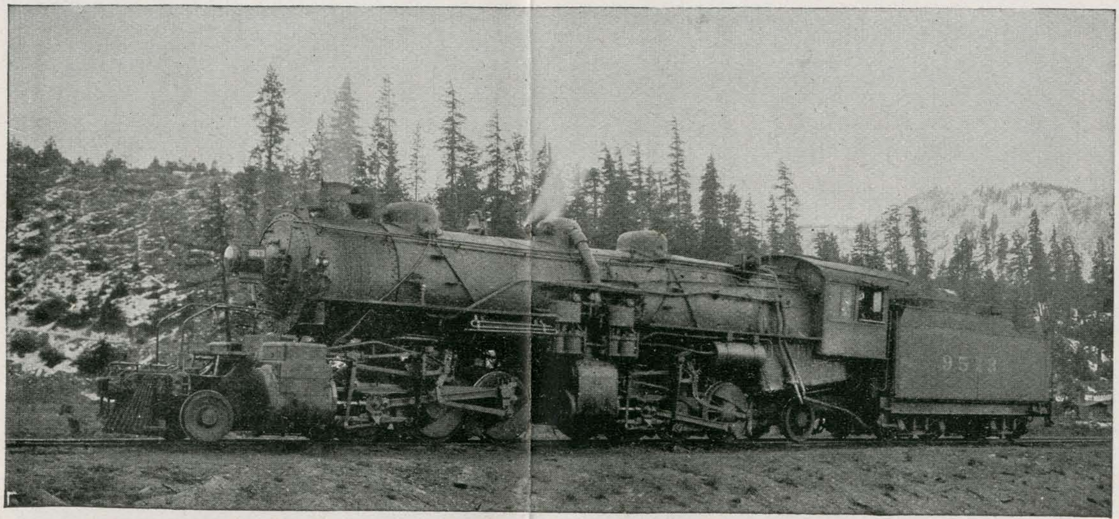
Washington Water Power Co. (60,000-volt transmission)	654
Puget Sound Traction, Light and Power Co. (55,000-volt transmission)	566

Transmission Line

The Railway Company's transmission line in general consists of three 2/0 B. & S. copper cables and one ⅜-inch S. M. steel strand ground wire supported on wooden poles, whose standard length on the level is 50 feet. The normal spacing of the poles on level tangents is 300 feet with maximum spans, depending on the line profile, of over 1,000 feet in length.



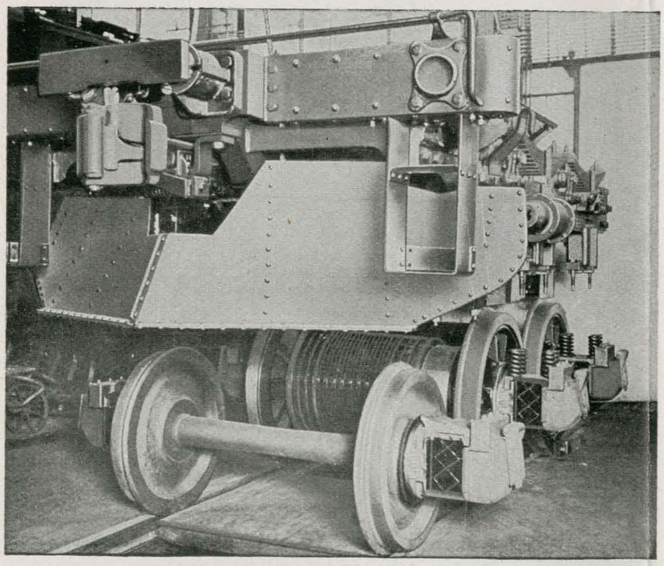
ANGLE TOWER ON 100,000-VOLT TRANSMISSION LINE



TYPE OF OIL-BURNING MALLET LOCOMOTIVE FORMERLY USED ON THE WESTERN DIVISIONS

Overhead Construction

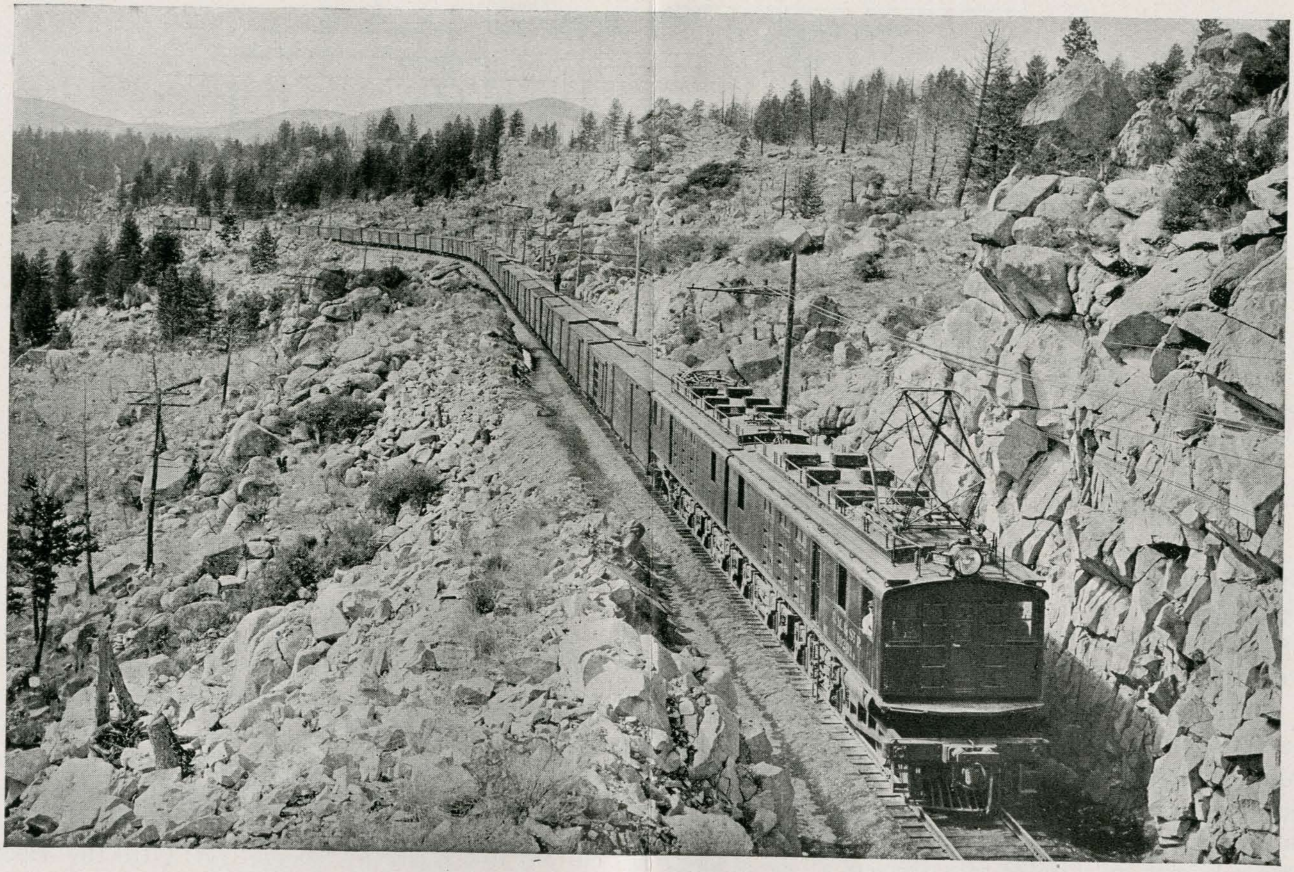
The overhead construction employed is of the flexible catenary type supported by suitably guyed and spaced wooden poles, the standard spacing on tangent single track being 150 feet. Bracket construction is used for single track, the poles at curves being located on the outside of the curve and the feeder and other wires on the cross arms, crossing over the track at right angles from one side to the other as necessary. In case, however, of a curve of short length, guyed span construction is used in preference to making a feeder crossing where this would otherwise be necessary. Similar guyed span construction is also used where there is more than one track, a steel cross catenary being employed to sustain the weight of the trolley wires and fixtures and, in case of more than two tracks, also a lower "steady" or horizontal span to preserve the wires in proper length as regards track centers. A special construction is used in tunnels, where the head room is small.



THREE-AXLE TRUCK OF GEARLESS LOCOMOTIVE PARTIALLY ASSEMBLED

The trolley catenary is a half-inch galvanized steel seven-strand wire and, on the main track, supports two 4/0 B. & S. grooved copper trolley wires, which hang side by side, this construction providing the requisite carrying capacity for the heavy trains which are used and also, on account of its freedom from "hard spots," enabling the current to be collected at high speeds with no sparking whatever. On side tracks a single 4/0 trolley wire is used. The standard height of the trolley wires above the top of rail is 24 feet, 2 inches.

To secure the minimum desired voltage drop, stranded copper feeder cables are used, mounted on the cross-arms of the trolley poles and consisting, except on mountain grades, of a single 500,000 circular mil cable. On mountain grades two 500,000 or two 700,000 circular mil cables are used. Trolley and feeder are sectionalized at the beginning and end of every passing track by means of section switches mounted on the poles and normally kept in closed position. In case of any trouble on any portion of the trolley system, adjacent section switches may be



FREIGHT TRAIN ASCENDING TWO PER CENT GRADE IN THE ROCKIES

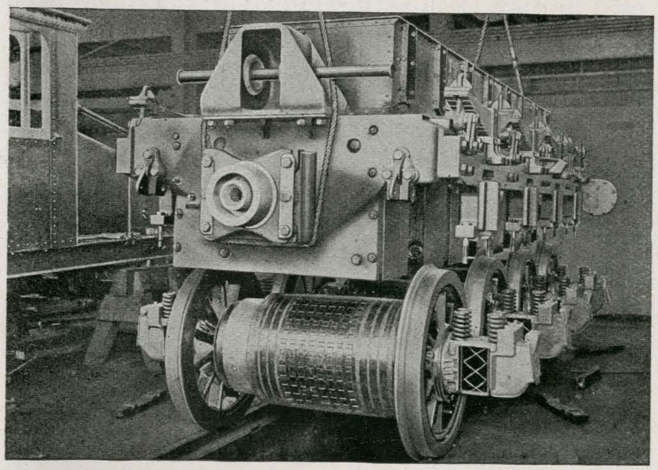
opened and such portions left de-energized, electric operation elsewhere being unaffected.

The return circuit for the traction current consists of the 85 or 90 pound running rail and a supplementary negative circuit consisting of a 4/0 B. & S. copper strand wire mounted on the poles and connected to the tracks through the signal circuit reactance bonds. Both rails of the main line are bonded and one rail of side tracks. One bond per joint is used except on mountain grades (grades over 1 per cent), where two bonds are used, either exposed or concealed, depending on the character of the rail joint. The auxiliary 4/0 return wire referred to above is mainly intended to act as a temporary shunt circuit for the rails in case, through any accident, the circuit through these rails themselves should become interrupted.

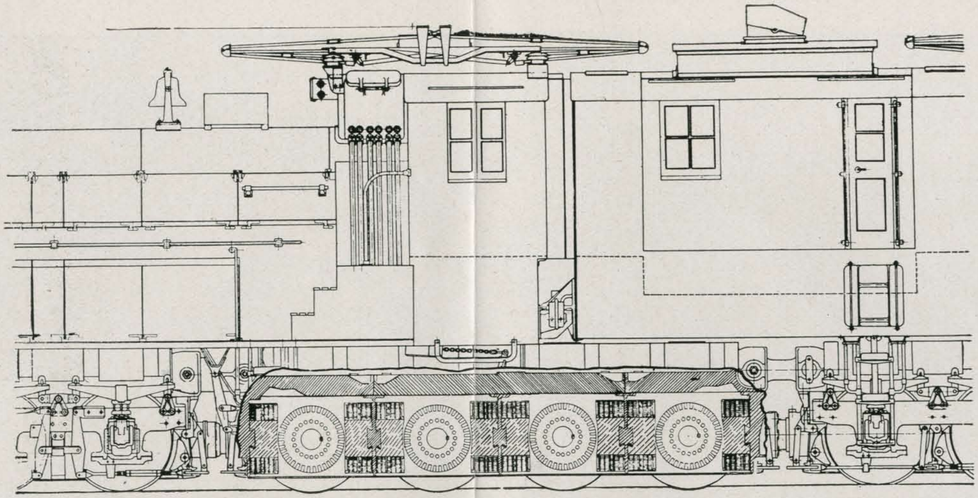
Signal System

The original direct-current light signals which existed during steam operation have been replaced by an automatic alternating-current signal system, using

signals of the light type in place of the previous semaphore type. This alternating-current system has



FOUR-AXLE TRUCK OF GEARLESS LOCOMOTIVE PARTIALLY ASSEMBLED



PART SECTION OF GEARLESS PASSENGER LOCOMOTIVE SHOWING MOTORS ON ONE OF THE FOUR-AXLE TRUCKS IN SECTION

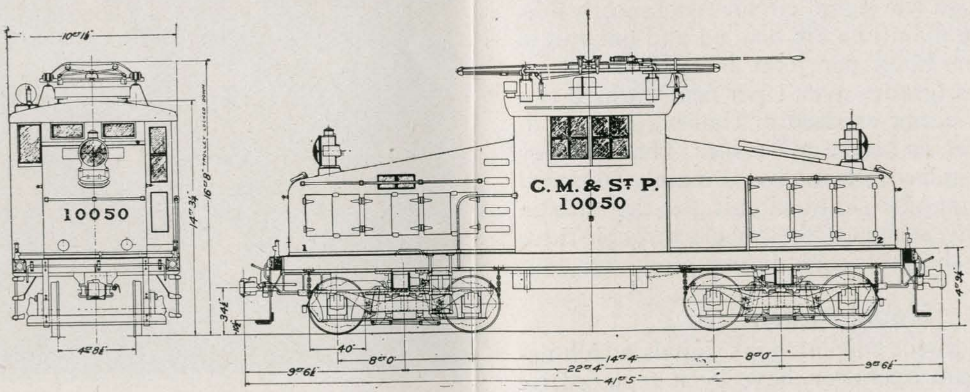
also been installed over portions of the line which were not previously controlled by automatic signals, so that now all of the electrified territory is equipped with the alternating-current light signal system.

This signal system is fed from two wires operating at 4,400 volts and mounted on the trolley poles adjacent to the power feeders. This circuit runs between adjacent substations and is fed by transformers in the latter. The 4,400-volt current is stepped down by suitable transformers at signal locations for the operation of the lights and track circuits.

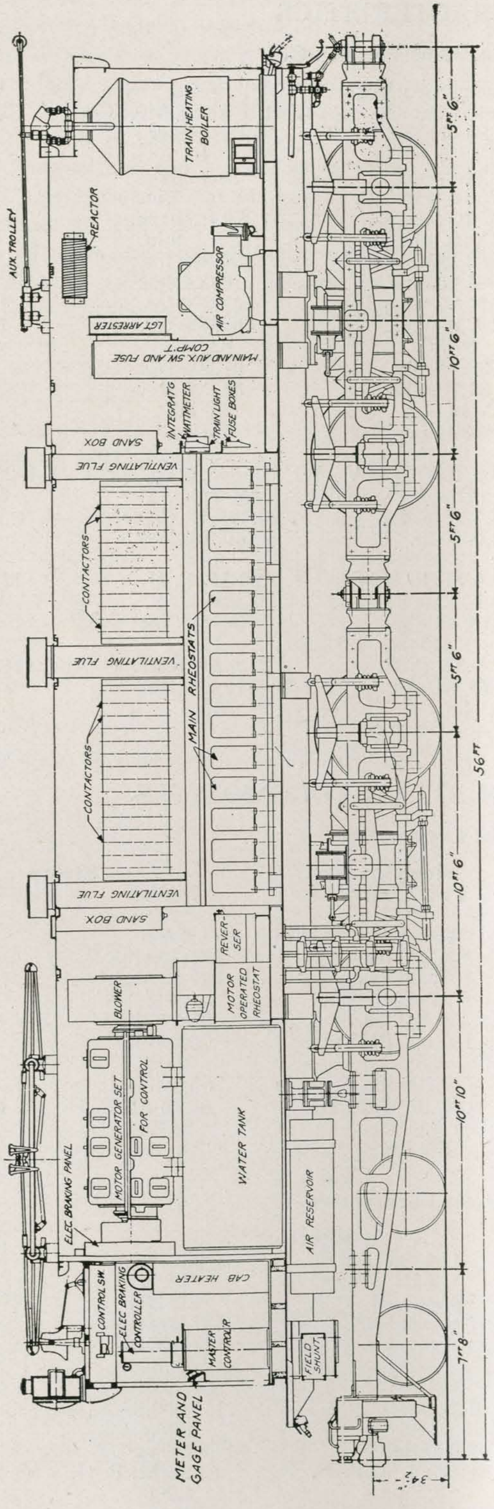
Copper Requirements

Copper is one of the most important materials used in connection with railway electrification. Such electrification involves, in general, the installation of four main facilities: (1st) the transmission system at which the railway receives the power which it purchased from the power company and by which this power is delivered to the various railway substations; (2d) the substations themselves, which are for the purpose of converting the high voltage current supplied by the transmission system to a suitable lower direct or alternating current voltage, which is delivered to the trolley system; (3d) the trolley system, which, together with its accompanying feeder system, supplies current to the electric locomotives; (4th) the electric locomotives, which propel the trains.

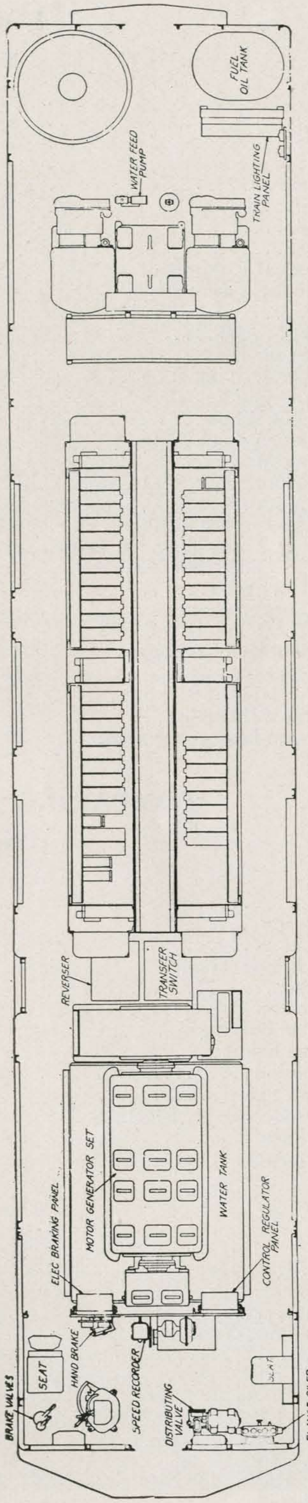
The amount of copper per mile which is used in the transmission system depends for any given amount of power to be delivered on the voltage of the system, which is so chosen that the total fixed and operating charges on the installation will be a minimum. The amount of copper used in the substations depends, of



DIMENSION OUTLINE OF 70-TON SWITCHING LOCOMOTIVE



ELEVATION OF HALF FREIGHT LOCOMOTIVE UNIT SHOWING ARRANGEMENT OF APPARATUS



PLAN OF HALF FREIGHT LOCOMOTIVE UNIT SHOWING ARRANGEMENT OF APPARATUS

LOCOMOTIVE CHARACTERISTICS

Normal Trolley Voltage, 3,000 Volts D. C.

Type of Drive	Twin Spring Gear	Bipolar Gearless	Quill Spring Drive	Solid Gear
Builder	Gen. Elec. Co.	Gen. Elec. Co.	West. Elec. & Mfg. Co.	Gen. Elec. Co.
Class	Freight	Passenger	Passenger	Switch
Number	42	5	10	4
Wheel Arrangement	44-4-4-44	24-8-8-42	462-264	4-4
Length over all	112 ft. 0 in.	76 ft. 0 in.	88 ft. 7 in.	41 ft. 5 in.
Total Wheel Base	102 ft. 8 in.	67 ft. 0 in.	79 ft. 10 in.	30 ft. 4 in.
Rigid Wheel Base	10 ft. 6 in.	13 ft. 9 in.	16 ft. 9 in.	8 ft. 0 in.
Weight of Mechanical Equipment	328,000 lbs.	286,550 lbs.	*297,000 lbs.	92,850 lbs.
Weight of Electrical Equipment	248,000 lbs.	*234,650 lbs.	270,000 lbs.	47,150 lbs.
Total Weight	576,000 lbs.	521,200 lbs.	567,000 lbs.	140,000 lbs.
Weight on Driver	451,000 lbs.	457,800 lbs.	367,600 lbs.	140,000 lbs.
Per cent of Weight on Driver	78%	87.5%	64.5%	100%
Average Weight per Driving Axle	56,400 lbs.	38,150 lbs.	61,300 lbs.	35,000 lbs.
Average Weight per Guiding Axle	31,000 lbs.	31,700 lbs.	33,200 lbs.	0
Diameter of Driving Wheel	52 in.	44 in.	68 in.	40 in.
Diameter of Guiding Wheel	36 in.	36 in.	36 in.	.....
Number of Driving Motors	8	12	6 (twin type)	4
Type of Driving Motors	GE 253, 1500/3000V	GE 100, 1000/3000V	WE&M 348, 1500/3000V	GE 255, 1500/3000V
Gear Ratio	82/18, 4.55	Direct	89/24, 3.71	64/17, 3.76
Continuous Rating—Total Output	3,000 H. P.	3,200 H. P.	3,400 H. P.	475 H. P.
Total Tractive Effort	70,700 lbs.	42,000 lbs.	49,000 lbs.	14,000 lbs.
Tractive Coefficient	15.7	9.18	13.0	10.0
Speed	15.9 M. P. H.	28.4 M. P. H.	26 M. P. H.	12.8 M. P. H.
Hourly Rating—Total Output	3,440 H. P.	3,500 H. P.	4,200 H. P.	670 H. P.
Total Tractive Effort	84,500 lbs.	48,500 lbs.	66,000 lbs.	22,400 lbs.
Tractive Coefficient	18.8	10.59	17.9	16.0
Speed	15.25 M. P. H.	27.1 M. P. H.	23.8 M. P. H.	11.2 M. P. H.
Tractive Effort Available at Starting	135,000 lbs.	123,500 lbs.	110,300 lbs.	42,000 lbs.
Tractive Coefficient at Starting	30	25	30	30

* Includes steam heat equipment.

COMPARING ELECTRIC WITH STEAM LOCOMOTIVES

Characteristics for Freight Locomotives

	Electric	Steam	
Type	Twin Gear	Mallet	Mikado
Railway Classification	EP1	N2	L2a
Wheel Arrangement	44-4-4-44	2660	282
Total Weight (including Tender)	576,000 lbs.	561,700 lbs.	443,700 lbs.
Weight on Drivers	451,000 lbs.	327,500 lbs.	216,400 lbs.
Per Cent of Weight on Drivers	78%	57%	49%
Average Weight per Driving Axle	56,400 lbs.	55,500 lbs.	54,100 lbs.
Maximum Tractive Effort	135,000 lbs.	76,200 lbs.	54,700 lbs.
Coefficient of Adhesion	30%	24%	27.8%
Tractive Effort and Speed at Continuous Rating for Electrics	70,700 lbs. @ 16 M. P. H.	55,000 lbs. @ 16 M. P. H.	43,000 lbs. @ 16 M. P. H.
Horsepower Developed	3,000	2,335	1,826
Pounds per Horsepower	192 lbs.	240 lbs.	243 lbs.

Characteristics for Passenger Locomotives

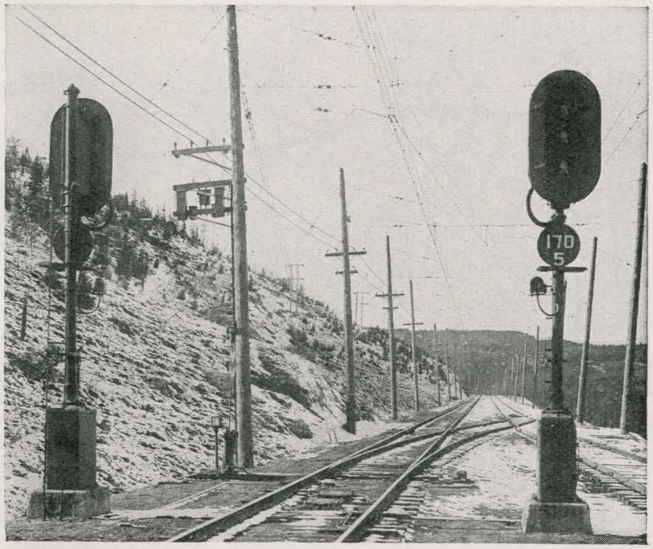
	Electric		Steam
Type	Gearless	Quill Drive	Pacific
Railway Classification	EP2	EP3	F5-an
Wheel Arrangement	24-8-8-42	462-264	462
Total Weight (including Tender)	521,200 lbs.	567,000 lbs.	406,167 lbs.
Weight on Drivers	457,800 lbs.	367,600 lbs.	160,000 lbs.
Per Cent of Weight on Drivers	87.5%	64.5%	39.4%
Average Weight per Driving Axle	38,150 lbs.	61,300 lbs.	53,333 lbs.
Maximum Tractive Effort	123,500 lbs.	110,300 lbs.	40,800 lbs.
Coefficient of Adhesion	25%	30%	25.5%
Tractive Effort and Speed at Continuous Rating for Electrics	42,000 lbs. @ 28.4 M. P. H.	49,000 lbs. @ 26 M. P. H.	25,500 lbs. @ 27.5 M. P. H..
Horsepower Developed	3,500	4,200	1,870
Pounds per Horsepower	149 lbs.	135 lbs.	217 lbs.

course, upon the number of substations and the number and capacity of the transformer units in each station. The amount of copper used in the trolley systems depends, of course, upon the number of miles of railway to be electrified, the voltage or system which is chosen on a basis similar to that used for determining the voltage for transmission system, and considering the amounts of power taken by the individual trains and by the total number of trains to be moved. The amount of copper will further depend upon the number of substations, and, again, the total number of substations and the corresponding total amount of copper used in the trolley system, respectively, are relatively so chosen so as to give the lowest ultimate economic cost.

The following tabulation has been prepared to show the amounts of copper used in the different facilities involved in the Chicago, Milwaukee & St. Paul Railway Company's electrification systems:

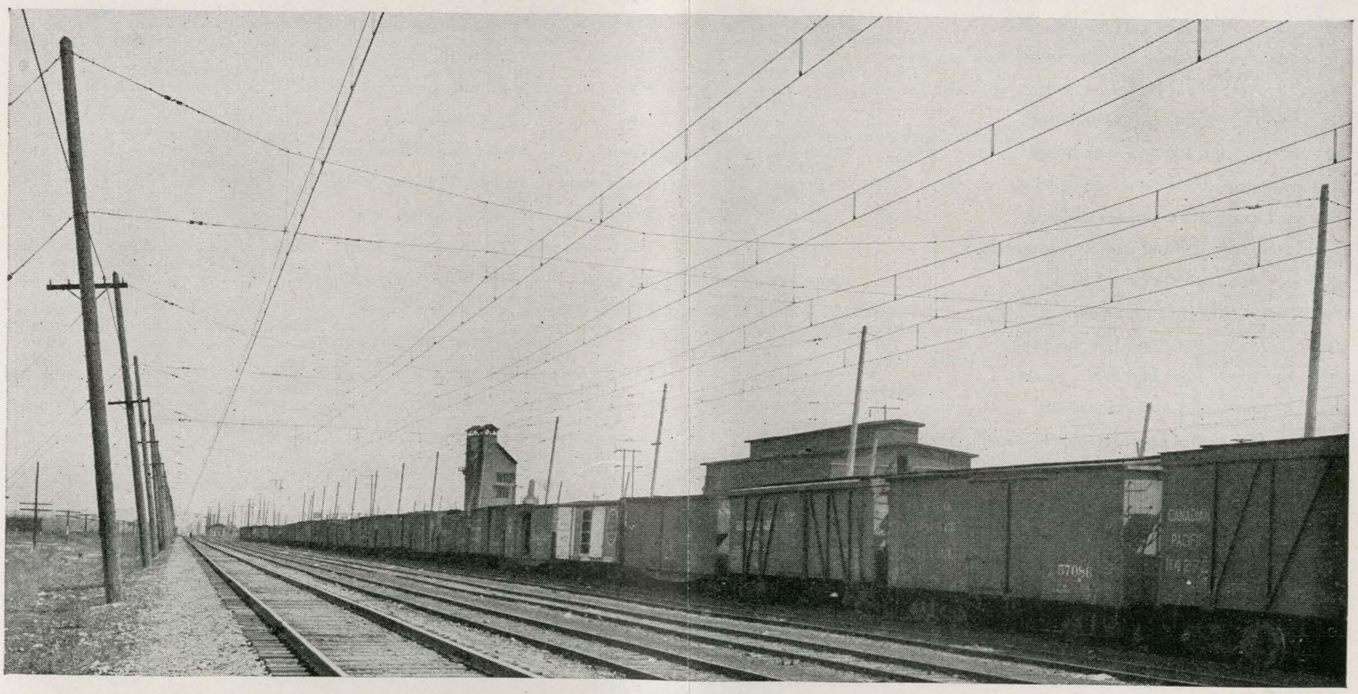
Substation apparatus	1,097,000 pounds
Locomotives	1,882,000 pounds
Transmission lines	3,540,000 pounds
Feeder and trolley lines	14,892,000 pounds
Signal circuits	944,000 pounds
Power indicating and limiting circuits	327,000 pounds
TOTAL	22,682,000 pounds

The amount of copper used for the different facili-

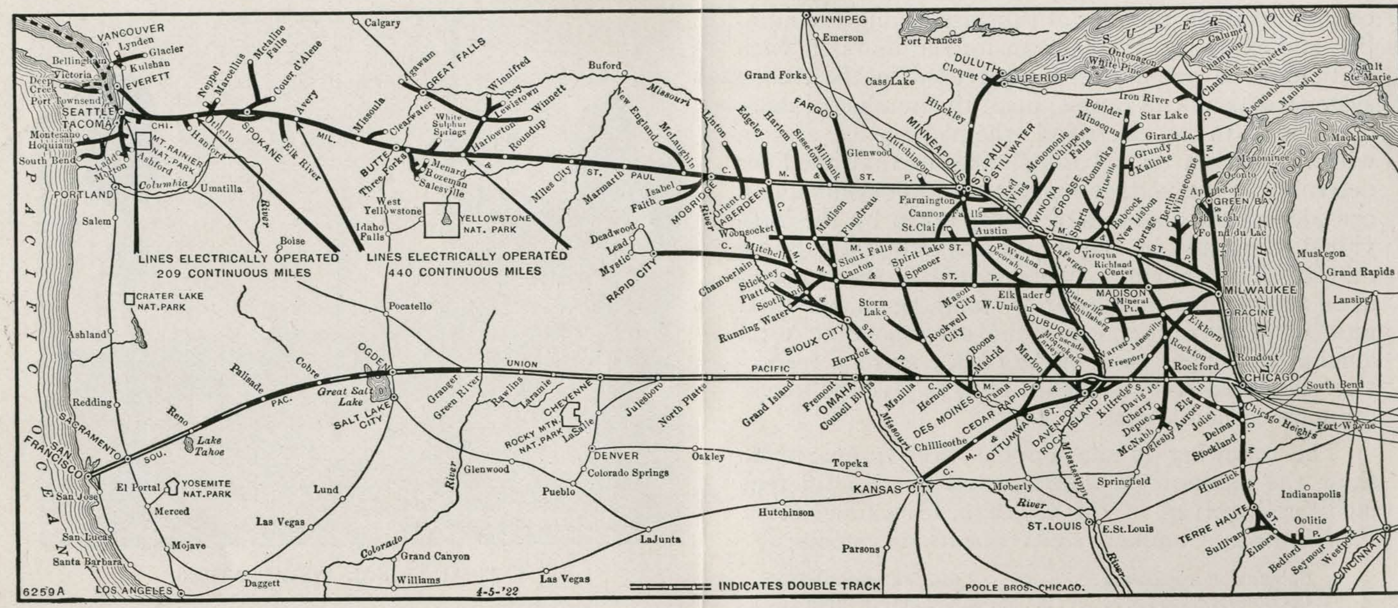


TYPICAL SIGNAL INSTALLATION

ties will, of course, vary with the traffic and other conditions which have to be considered in a particular case, but the amounts given above as used in the C. M. & St. P. Railway Company's electrification are amply sufficient to allow for future normal expansion of traffic.



CROSS SPAN OVERHEAD YARD INSTALLATION



Information regarding railway and sleeping car fares, train schedules, etc., may be obtained from any of the representatives of the Chicago, Milwaukee & St. Paul Railway named below:

ABERDEEN, S. D., Passenger Station, 1 North Main Street........Phone 2325
O. F. Waller..................................Division Passenger Agent
ABERDEEN, WASH, 212 South H Street..........................Phone 221
W. R. Rehm....................................City Passenger Agent
BELLINGHAM, WASH., Railroad Avenue..........................Phone 616
Geo. W. Blair...............................Traveling Passenger Agent
BOSTON, (9) MASS., 552 Old South Building............Phone Congress 1308
F. D. Dodge...General Agent
BUFFALO, N. Y., 325 Ellicott Square....................Phone Seneca 590
R. F. Trumper...............................Traveling Passenger Agent
BUTTE, MONT., Passenger Station, South Montana Street........Phone 5800
P. J. Peckens................................Division Passenger Agent
CEDAR RAPIDS, IOWA, Passenger Station, 401 First Avenue........Phone 307
J. L. Coffey..General Agent
CHICAGO, ILL., 620 Marquette Building...............Phone Harrison 6162
F. N. Hicks....................General Agent Passenger Department
CINCINNATI, OHIO, 103 Neave Building..................Phone Main 5010
B. O. Searles...General Agent
CLEVELAND, OHIO, 416 Swetland Building.............Phone Prospect 4174
F. E. Clark...General Agent
DALLAS, TEXAS, 302 Insurance Building.....................Phone X 5291
J. M. Allen...General Agent
DAVENPORT, IOWA, Front and Ripley Streets...............Phone Dav 880
A. Mallum...General Agent
DENVER, COLO., 516 Denham Building...................Phone Main 7940
A. A. Wilson..General Agent
DES MOINES, IOWA, Union Station.....................Phone Walnut 1708
H. W. Warren................................District Passenger Agent
DETROIT, MICH., 403 Free Press Building................Phone Main 6835
H. W. Steinhoff...General Agent
DUBUQUE, IOWA, Fifth and White Streets..............Phone Dubuque 174
M. H. McEwen.................................Division Passenger Agent
DULUTH, MINN., 800 Alworth Building.................Phone Melrose 403
G. M. Bowman..General Agent
EVERETT, WASH., 32d and McDougal Streets...Phones Exchange 195 and 196
H. H. Tavenner..................................General and Local Agent
GREAT FALLS, MONT., 2d Avenue and 3d Street South..Phones 9669 and 9712
H. R. Wahoske................................Division Passenger Agent
GREEN BAY, WIS., C. M. & St. P. Passenger Station............Phone 5000
H. E. Stewart................................Division Passenger Agent
KANSAS CITY, MO., 723 Walnut St...Phones, Bell 6390, Home, Harrison 2546
E. G. Woodward...................General Agent Passenger Department
LIVERPOOL, ENGLAND....................18 Chapel Street; 9 James Street
J. Jackson & Sons..European Agents
LONDON, ENGLAND..7-8 Charing Cross
J. Jackson & Sons..European Agents
LOS ANGELES, CAL., 422 Van Nuys Building................Phone 820-855
H. W. Porter..General Agent

MADISON, WIS., C. M. & St. P. Passenger Station........Phone Badger 6300
W. W. Winton................................District Passenger Agent
MASON CITY, IOWA, 9th Street and South Pennsylvania Avenue, Phone 230-J
W. F. Cody...................................Division Passenger Agent
MILES CITY, MONT., Foot of Eighth Street...................Phone 476-R
M. E. Randall...............................Traveling Passenger Agent
MILWAUKEE, WIS., 405 East Water Street............Phone Broadway 5720
E. G. Hayden....................General Agent Passenger Department
MINNEAPOLIS, MINN., 526 Second Avenue, South..........Phone Main 5652
T. A. Morken....................................City Passenger Agent
MISSOULA, MONT., Higgins Avenue and Third Street............Phone 319
C. E. Tyndall...............................Passenger and Ticket Agent
NEW ORLEANS, LA., 912 Hibernia Bank Building..........Phone Main 6449
W. H. Rogers..General Agent
NEW YORK, N. Y., 42 Broadway.........................Phone Broad 6600
G. L. Cobb.......................General Agent Passenger Department
OMAHA, NEB., 306 South Sixteenth Street..............Phone Douglas 4481
W. E. Bock.......................General Agent Passenger Department
PHILADELPHIA, PA., 1309 Finance Building..........Bell Phone Spurce 2155
Geo. J. Lincoln...General Agent
PITTSBURGH, PA., 3110 Jenkins Arcade..................Phone Grant 4998
T. P. Casey...General Agent
PORTLAND, ORE., 1107 Gasco Building...................Phone Main 2034
R. L. Ford..General Agent
ST. LOUIS, MO., 2002 Railway Exchange....................Phone Olive 337
C. J. Peterson..General Agent
ST. PAUL, MINN., 365 Robert Street.....................Phone Cedar 4491
L. M. Jones......................General Agent Passenger Department
SALT LAKE CITY, UTAH, 503 Clift Building............Phone Wasatch 3625
C. S. Williams..General Agent
SAN FRANCISCO, CAL., 995 Monadnock Building........Phone Kearney 1758
C. H. Miles......................General Agent Passenger Department
SEATTLE, WASH., 663 Stuart Building....................Phone Main 6960
A. P. Chapman, Jr..................Assistant General Passenger Agent
SIOUX CITY, IOWA, 503 Fourth Street.........................Phone 2689
C. N. Curtis.................................Division Passenger Agent
SPOKANE, WASH., Sprague Ave. and Post Street...Phones Main 125 and 4100
W. P. Warner.................................Division Passenger Agent
TACOMA, WASH., 110 South Tenth Street.................Phone Main 2100
E. A. Lalk...................................Division Passenger Agent
TERRE HAUTE, IND., Rea Building.....................Phone Wabash 1296
P. M. Fagan..................................Division Passenger Agent
VANCOUVER, B. C., 626 Hastings Street, West...........Phone Seymour 165
Geo. W. Hibbard...General Agent
VICTORIA, B. C., 902 Government Street........................Phone 92
F. O. Finn..General Agent
WINNIPEG, MAN., 1208 McArthur Building.................Phone A 3161
E. Mathern..................................Traveling Passenger Agent

GEO. B. HAYNES
General Passenger Agent
Chicago, Ill.

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