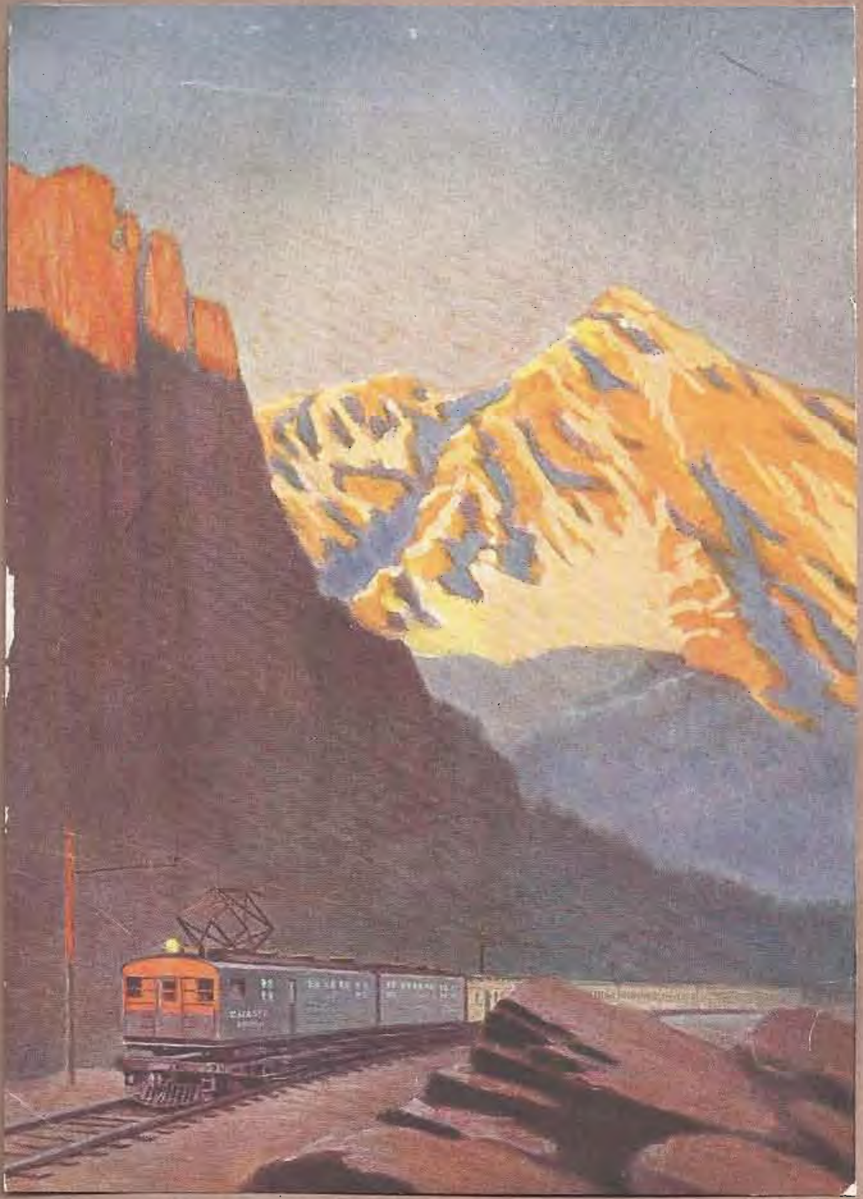
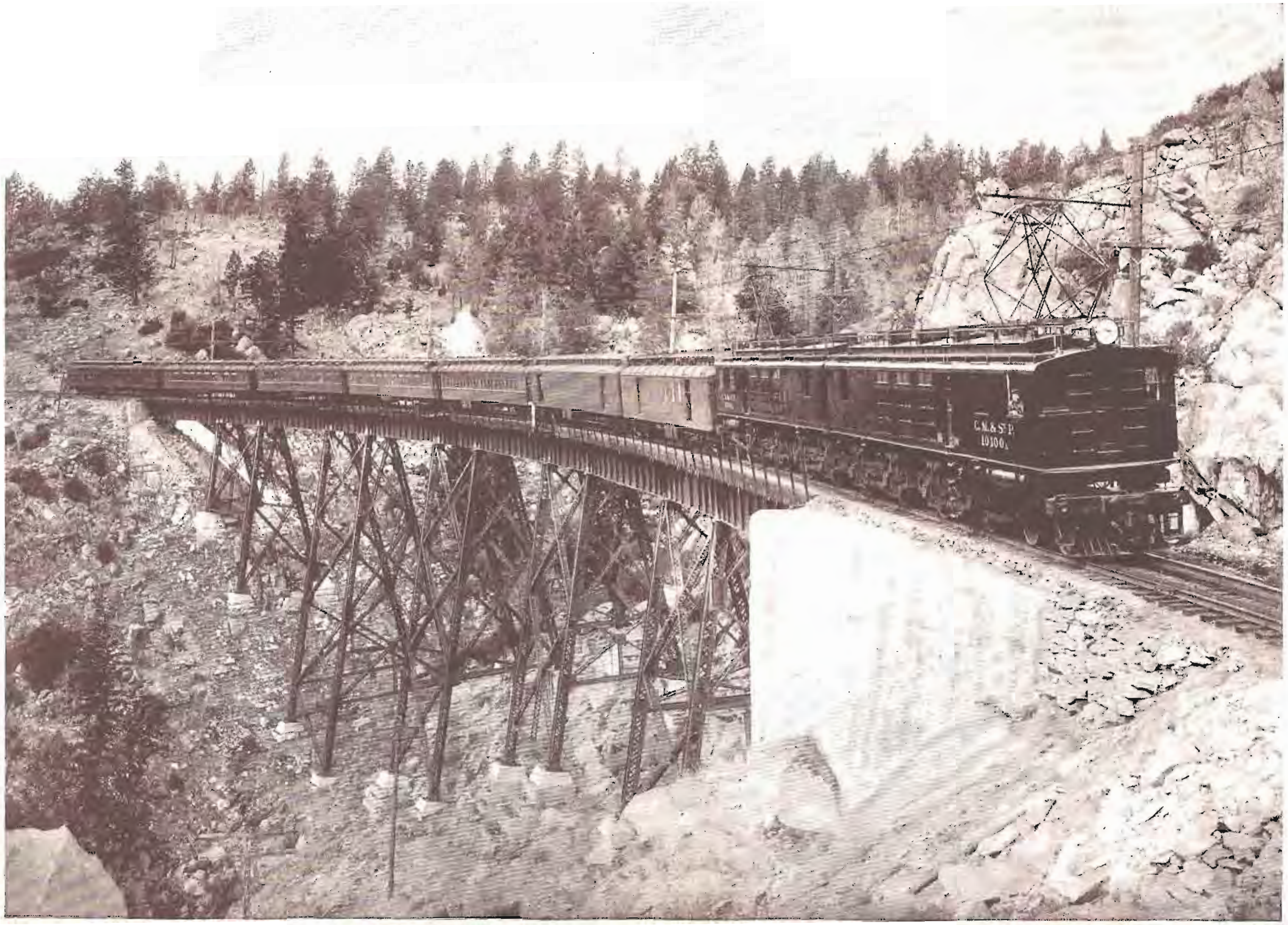


An Epoch in Railway Electrification

An Epoch in Railway Electrification



TRANSCONTINENTAL PASSENGER TRAIN "OLYMPIAN"
DESCENDING EAST SLOPE OF THE ROCKIES

An Epoch in Railway Electrification

GENERAL ELECTRIC COMPANY
SCHENECTADY NEW YORK

July, 1910

Bulletin No. 41913

Freight Train at Donald, the Summit of the Continental Divide

An Epoch in Railway Electrification

THERE are no more thrilling and fascinating stories in American history than those of the great transcontinental railway system. Masterly planning, unprecedented financing and marvelous engineering skill distinguished the early attempts to break through the great natural barrier between the Great Lakes country and the Pacific Coast. The execution of these plans, extending over a long period of years, was a series of most remarkable accomplishments. Brilliant pioneering exploits marked the progress of surveyors, road builders, and operating force through the wilderness of mountains and desert. In the operation of the transcontinental railroad most serious problems have been encountered in lifting the fast increasing tonnage over the mile-high Rocky Mountain Divide. In winter the deep snows and excessively cold weather have imposed almost insuperable obstacles.

The Electrical Era

The present era is eminently the electrical era. Electricity mines and refines our ores, turns the wheels of our manufacturing plants, lights our cities and towns, transmits our messages, moves our urban and interurban cars, and when produced by water power it conserves our rapidly diminishing supply of coal. The change from steam to electricity for railroad transportation is not a theorist's fancy or a railroad president's whim; it is the logical result of electricity coming into its own. All the achievements in transcontinental railroad transportation in the past—and they have been many and marvelous—have been accomplished with steam locomotives, but today the steam locomotive is outclassed in power, in flexibility, in reliability, in ease of control, in economy, in comfort and in substantially every feature, by the electric locomotive. Therefore, the electrification of transcontinental railroads is a natural product of the electrical era.

Nevertheless, it is a brilliant mile post on the road of progress in railroading, and there is more than a coincidence in the fact that the Chicago, Milwaukee & St. Paul Railway, which has many great pioneer achievements to its credit, should realize in actual accomplishment the aspirations cherished by the exponents of electricity decades ago.

While many terminal and tunnel installations have been made in the past for the purpose of eliminating smoke, taking care of suburban traffic or other local conditions, the Chicago, Milwaukee & St. Paul electrification is the first project of the kind where electric locomotives were installed to operate over several engine divisions.

The Electrified Divisions

Electric Zone

The tracks of the mountain district of the Chicago, Milwaukee & St. Paul Railway, in surmounting the obstacles imposed by the Rocky Mountain and coastwise ranges, represent the solution of one of the most difficult problems ever mastered by railway engineers. Out of this section of rugged mountain railway, including many long grades and short radius curves, four steam engine divisions were selected for electrification, aggregating 440 miles in length. Steam engines were first abandoned on the Three Forks-Deer Lodge division, 115 miles long, and crossing the main Continental Divide, thus giving the electrical equipment its initial tryout under the severest service conditions of the entire system. The first electric locomotives were placed in regular service on December 9, 1915, and during the month of April, 1916, service was extended to Harlowton, making a total of 220 miles of electrically operated road. By the first of November, 1916, it is expected that steam engines will be superseded over the entire distance of 440 miles from Harlowton, Montana, to Avery, Idaho.

This project is the most extensive steam railway electrification in the world, the length of haul being nearly six times as great as any trunk line now operating with electric locomotives. The length of track between Harlowton, Montana, and Avery, Idaho, is approximately equal to that from New York to Buffalo or from Boston to Washington.

In crossing the three mountain ranges included in the electric zone, 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 on the west slope of the Belt Mountains.

The curvature is necessarily heavy, the maximum being 10 degrees. There are also numerous tunnels in the electric zone, 36 in all, of which the longest is the St. Paul Pass tunnel, over a mile and a half in length, through the ridge of the Bitter Root Mountains.

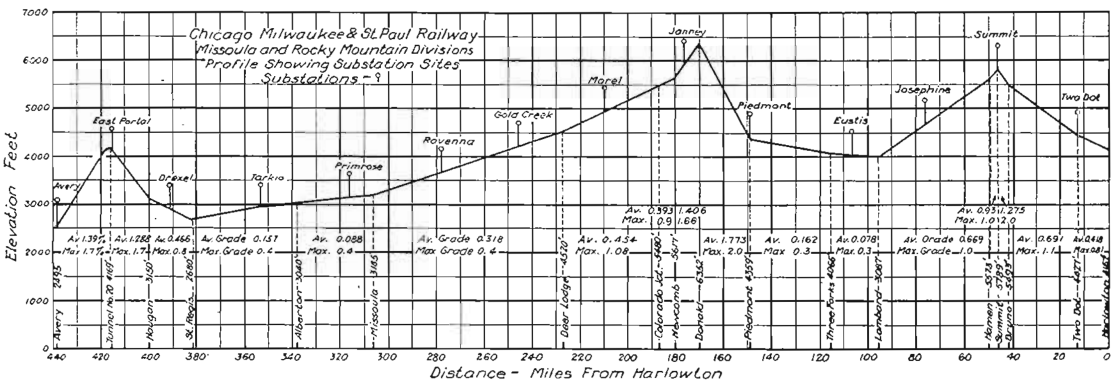
Passenger & Freight Traffic

The passenger service consists of two all-steel finely equipped transcontinental trains in each direction, the "Olympian" and "Columbian," and a local passenger train in each direction daily between Deer Lodge and Harlowton.

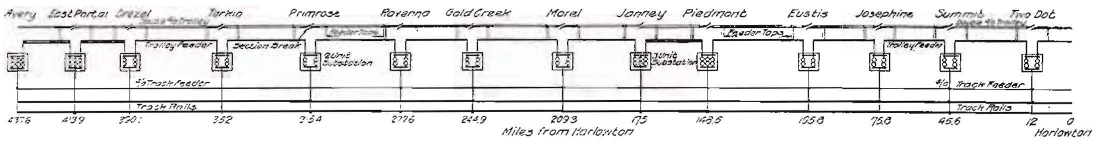
Freight traffic through the electric zone comprises from four to six trains daily in each direction. Westbound, the tonnage is made up of manufactured products and merchandise for Pacific Coast points and foreign shipment. Eastbound tonnage includes grain, lumber, products of the mines and some live stock.

Freight Train Ascending Two Per Cent Grade

As a larger part of the traffic is *through* freight, trains are 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. These cars being owned by many different railway systems are equipped with air brakes adjusted for different conditions of operation, and in accordance with different standards



Profile of Electric Zone



Direct Current Distribution

Trans-continental Passenger Train "Olympian" Climbing the Rockies Before Electrification

as to braking power and type of equipment, thus making the problem of holding the long trains on the heavy down grades by air brakes a most difficult one.

Electrical Operation

Electrification promises a material reduction in running time. It has been found, for example, that on the 21 mile two per cent grade from Piedmont to Donald, the electric locomotive can reduce the running time of passenger trains from an hour and five minutes to approximately 40 minutes. On the run from Deer Lodge to Butte which, under the steam locomotive schedule, required an hour and 20 minutes, a saving of approximately 30 minutes can be made.

In the freight service, it has been found that on the first division where the steam locomotives have required 10 to 12 hours to make 115 miles, electric locomotives can meet a schedule of from seven to eight hours for the same distance. The heavy grades and frequent curves at certain points offer serious obstacles to steam locomotive operation even in the summer time, but with winter temperatures as low as –40° F. and heavy snowfalls in the Bitter Root Mountains, serious delays have occurred, owing to engine failures or to inability to make steam. The capabilities of the electric locomotives are in no way impaired by cold weather or by inability to obtain fuel or water in case of snow blockades. During a series of record-breaking temperatures in December, 1915, Mallet engines were frozen up at different points on the system and the new electric equipment was rapidly pressed into service to replace them. On several occasions electric locomotives hauled in disabled steam engines and trains which would otherwise have tied up the line.

Train of Eighty-two Freight Cars in Silver Bow Canyon

During initial operation on the Rocky Mountain division, the capacity of the new locomotives has been thoroughly tested. Trains of 3000 tons trailing have been hauled east and 2800 tons west, using a helper on the heavy grades. From the operating data obtained on the first division, it is evident that much heavier trains can be

All-steel Passenger Train "Olympian" at Deer Lodge

EAGLE NEST TUNNEL IN SIXTEEN MILE CANYON

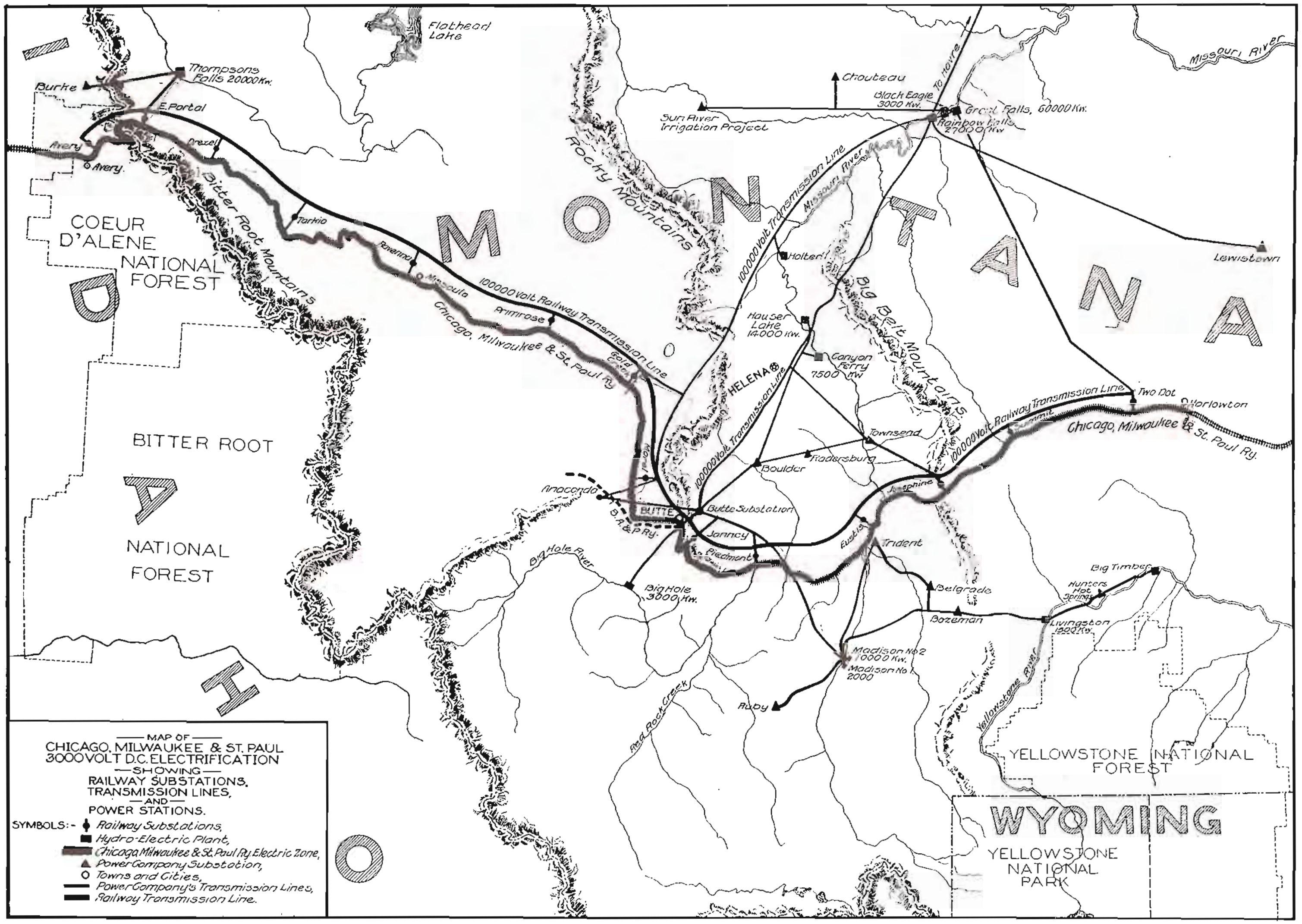
Eustis Substation and Operators' Bungalows

hauled with the electric locomotives than with steam engines, and all passing tracks are being lengthened to take advantage of longer trains. On some of the runs where the grades are less than one per cent trains of as many as 130 cars and as heavy as 4000 tons have been hauled with a single locomotive.

The four through passenger trains, "Olympian" and "Columbian," are taken across the two mountain ranges by a single passenger locomotive. These trains at present consist of eight full vestibuled steel coaches, weighing approximately 650 tons. Instead of changing locomotives at Three Forks, as has been the practice under steam operation, the same locomotive is run through the 220 miles from Deer Lodge to Harlowton, changing crews midway. Passenger trains will travel over the entire electrified division in approximately 15 hours, including all stops, and the tourist thus will have an opportunity of traversing by daylight some of the most beautiful scenic regions in the United States and without suffering the annoyance of cinders and smoke incident to the use of steam locomotives.

The local passenger train operating in the electric zone between Deer Lodge and Harlowton is handled by a half unit weighing about 150 tons with equipment similar to the main line locomotives.

Concerning the first few months of operation, Mr. C. A. Goodnow, assistant to the President of the Chicago, Milwaukee & St. Paul Railway, in charge of the electrification, has 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."



MAP OF MOUNTAIN DISTRICT, CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

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 three 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, and it approximates 3500 kw. or 4700 h.p. for a 2500 ton train running at 17 miles per hour on a two per cent grade, thus 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:

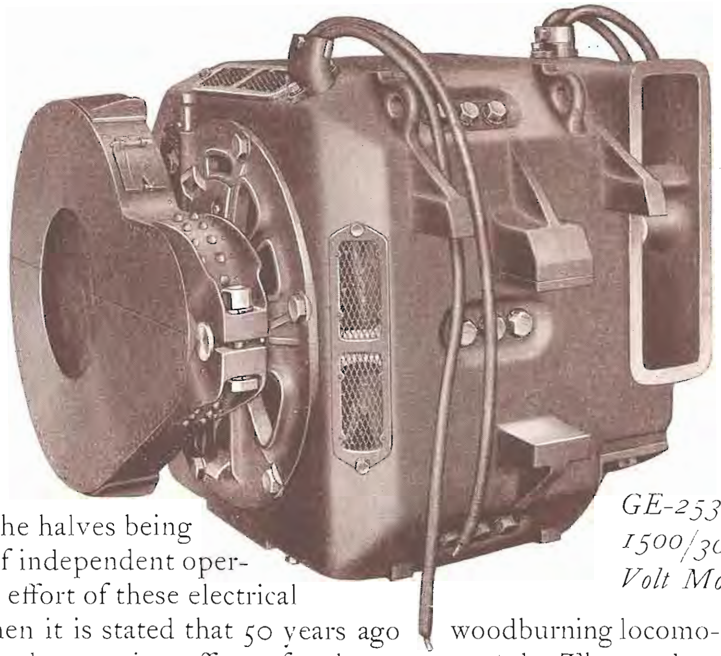
- Elimination of difficulties incident to the use of air brakes on heavy freight trains when descending mountain grades.
- Elimination of brake shoe and wheel wear with resultant reduction in maintenance.
- Reduced wear on tracks, especially on severe curves.
- A probable saving of approximately 15 per cent in the total power consumption.
- Maximum safety in operation assured by a duplicate braking system relieving the air brakes.
- The entire absence 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.

The Electrical Equipment

The scheme of electrification includes the generation of electricity from the several water power plants of the Montana Power Company; transmission at 100,000 volts, three-phase, 60 cycles; conversion in the substations to 3000 volts direct current and distribution to electric locomotives over catenary overhead construction.

Electric Locomotives

The achievement which has made the electrification of trunk lines feasible is primarily the development of the electric locomotive.



GE-253-A 1500/3000-Volt Motor

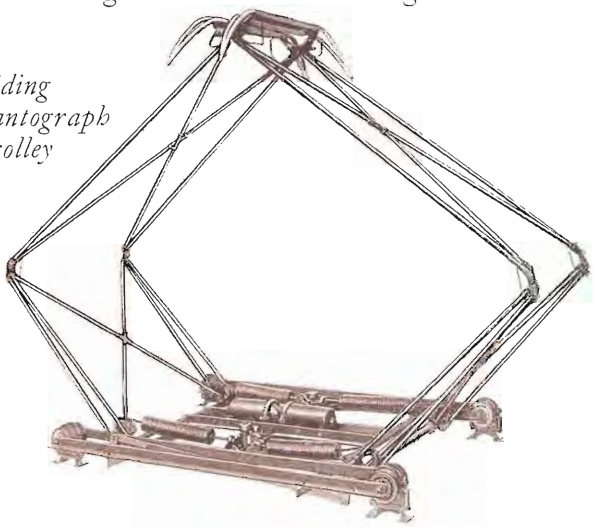
The main line Chicago, Milwaukee & St. Paul Railway electric locomotives are constructed in two units permanently coupled together, the halves being duplicates and each capable of independent operation. The enormous tractive effort of these electrical giants will be appreciated when it is stated that 50 years ago woodburning locomotives weighed 20 tons and had a tractive effort of only 5000 pounds. The modern Mallet steam locomotive weighing 278 tons with tender, which has been released, has a tractive force of 76,200 pounds, while the electric locomotive, weighing 282 tons, has a running tractive force of 85,000 pounds or a starting tractive force of 136,000 pounds.

Spring Gear

There are 42 of these main line locomotives (30 freight and 12 passenger) and two switching locomotives. The locomotives are the first to be used for railroad service with direct current motors operating at a potential as high as *3000 volts and the first to use direct current regeneration. The passenger locomotives are equipped with a gear ratio permitting the operation of 800-ton trailing trains at speeds of approximately 60 miles per hour on tangent level track. The average passenger train

* It is of interest to note that this is the first direct current installation to use a potential as high as 3000 volts, and this equipment was adopted after a careful investigation of all systems available for electrification. The Butte, Anaconda & Pacific Railway, in the immediate vicinity of the Chicago, Milwaukee & St. Paul electrification, has been in operation with 2400-volt direct current locomotives since May, 1913, and has furnished an excellent demonstration of the entire practicability of high-voltage direct current operation.

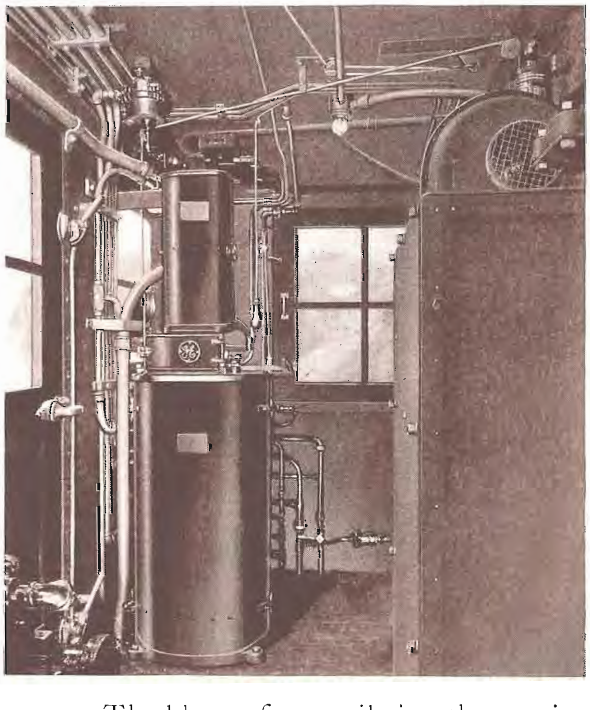
weighs from 650 to 700 tons and is hauled over the two per cent grade without a helper. The freight locomotives are designed to haul a 2500 ton trailing train at approximately 16 miles per hour on all grades up to and including one per cent. On two per cent grades the trailing load was limited to 1250 tons, although this figure has been exceeded in actual operation.



Sliding Pantograph Trolley

Motors and Control

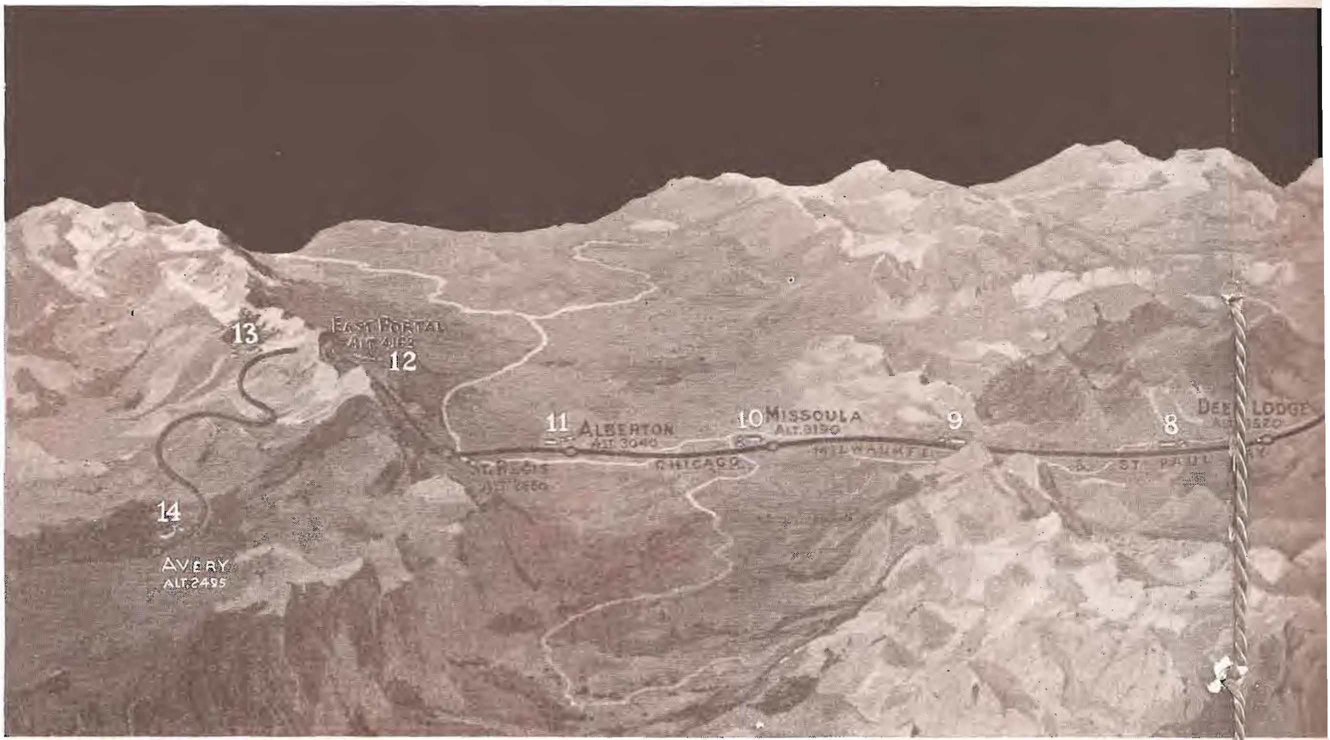
Each locomotive is equipped with eight Type GE-253-A, 1500-volt motors, insulated for 3000 volts to ground. This motor has a normal one hour rating of 430 h.p. and a continuous rating of 375 h.p., so that the locomotive power plant has a normal one hour rating of 3440 h.p. and a continuous rating of 3000 h.p. Each motor is twin geared to its driving axle in the same manner as on the Butte, Anaconda & Pacific, the Detroit River Tunnel, and the Baltimore & Ohio locomotives, a pinion being mounted on each end of the armature shaft. Additional 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 and is constructed with longitudinal ventilating ducts in the armature for forced ventilation from a blower in the cab.



Engineer's Cab

The control equipment is the well-known Sprague General Electric Type M arranged for multiple unit operation. The main control switches are mounted in steel compartments inside of the locomotive cab with convenient aisles for inspection and repairs. In each half of the locomotive a motor-generator set furnishes low-voltage current for the control circuits, headlights, cab lighting and for charging the storage batteries on passenger coaches. Under steam operation, the charging current for these batteries is furnished by the steam turbo-generator set located in the baggage car. The blower for ventilating the traction motors is also direct connected to one end of this set.

Relief Map of Rocky Mountain District Showing Location of Substations



The pantograph collectors, one of which is mounted on each half of the locomotive, are of the double pan type with a working range of from 17 feet 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.

The air brake equipment is practically the same as that used on steam locomotives except that motor driven air compressors are used to furnish compressed air. Aside from the air brakes, compressed air is also used for signals, whistles, bell-ringers, sanders, flange oilers, pantograph trolleys, part of the control equipment, and on the passenger locomotives for the oil-fired steam boilers.

Switching Locomotives

The switching locomotives are of the swivel truck type, weighing 70 tons each, and equipped with four geared motors. A single pantograph of construction similar to that used on the main line locomotives is mounted on the cab and in other ways the locomotives represent the standard construction commonly used with the steeple cab type of switcher. The motors (known as Type GE-255) are of box frame, commutating-pole, single-geared type designed for 1500 volts with an insulation of 3000 volts to the ground. Many of the switching locomotive parts are interchangeable with those used on the main line locomotives; for example, the air compressors, small switches, headlights and cab heaters.

Source of Power

Utmost precautions were taken by the Railway Company in making plans for this electrification to insure a reliable source of power. The Montana Power Company, with

Chicago, Milwaukee & St. Paul Railway

whom the contract was closed for electric power, operates a network of transmission lines covering a large part of Montana, which are fed from a main plant at Great Falls, and a number of other widely separated water power plants of adequate capacity at all seasons of the year. A notable feature of this pioneer electrification is, therefore, the conservation of fuel consequent upon the utilization of water powers.

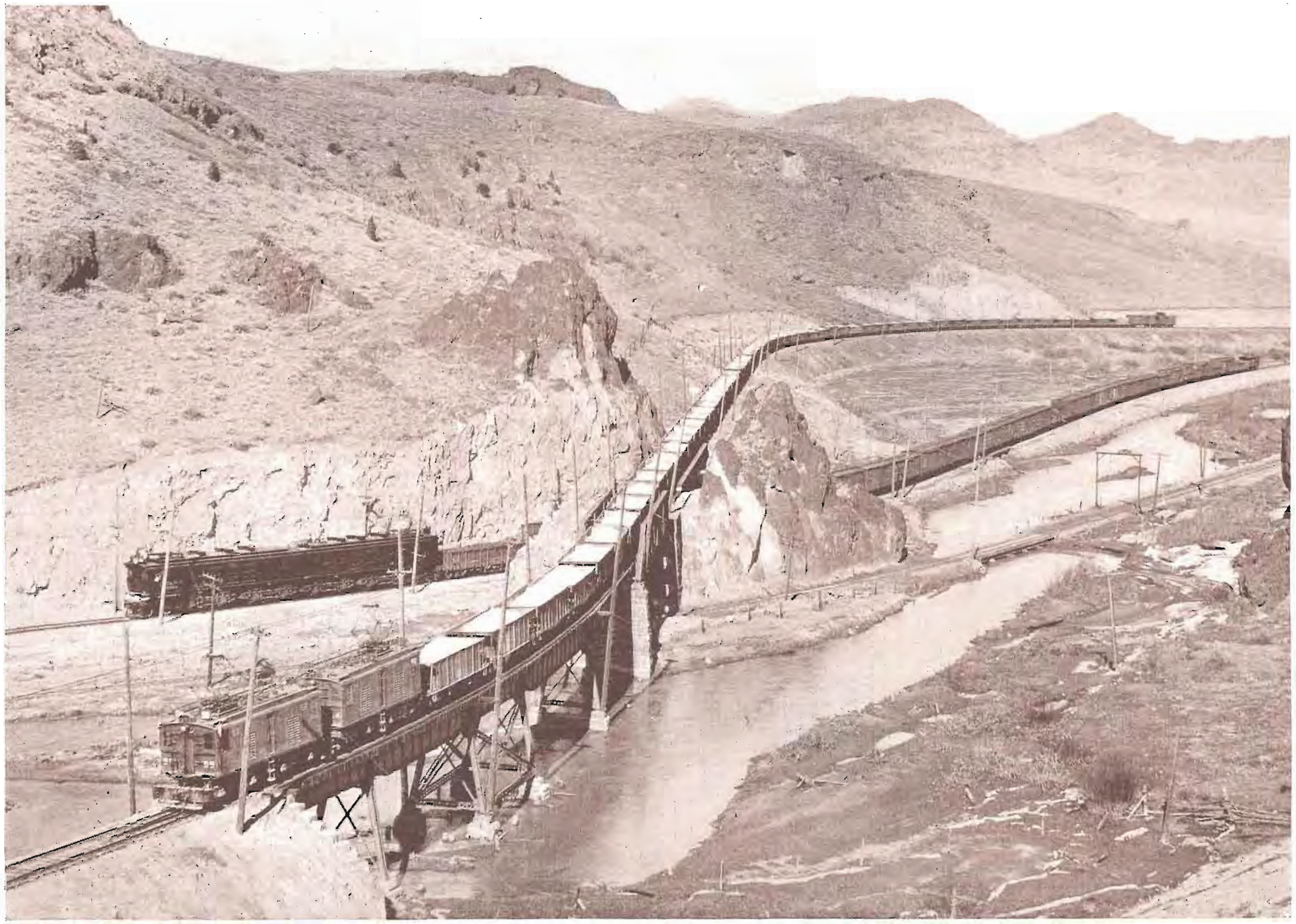
Transmission Lines

The Montana Power Company's transmission lines, which are carried in some cases on steel towers and in others on wooden poles, tap into the railway system at seven different points where the power is most needed. The Railway Company's transmission line extends the entire length of the system on wood poles. In most cases this line is built on the Company's right-of-way, although at several points there are cutoffs which make a considerable saving in the length of line.

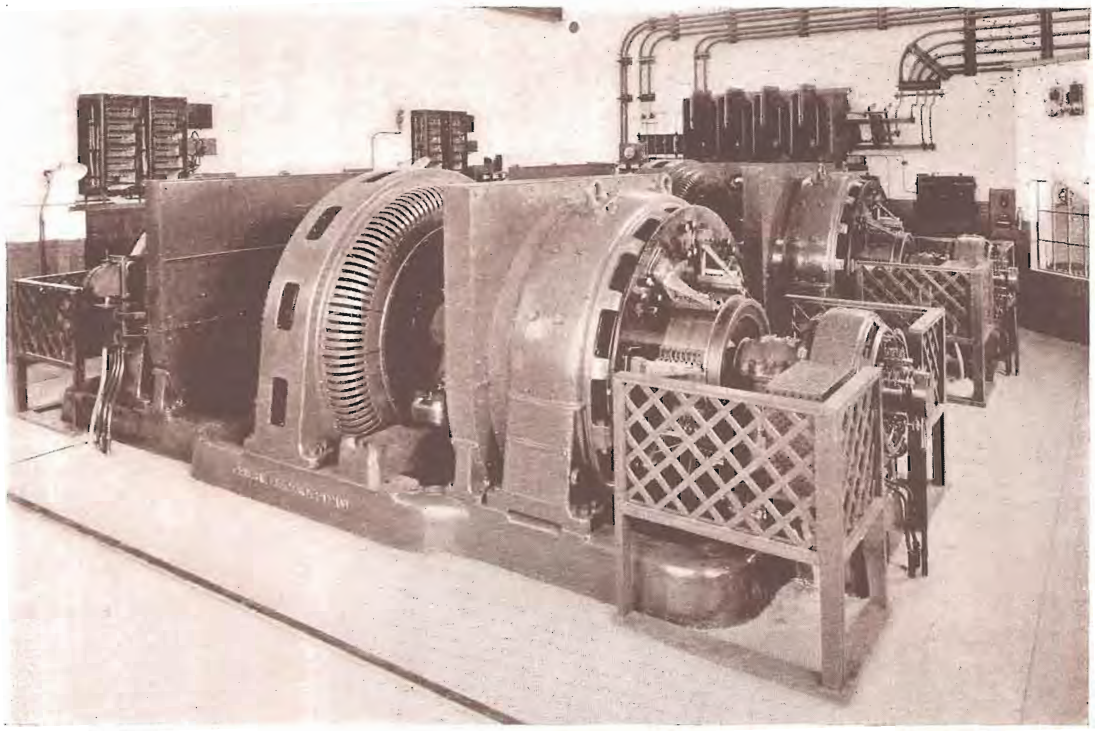
With this completely inter-connected transmission system, each substation may be fed from either direction and also at the tie-in points from a third source of power.

Substations

Fourteen substations are equipped for converting the 100,000-volt alternating current to 3000 volts direct current. They are distributed along the route at average intervals of 32 miles. Each station contains step-down transformers, motor-generator sets, switchboard and the necessary controlling and switching equipment. The transformers receive the line current at 100,000 volts and supply the synchronous motors at 2300 volts. Each synchronous motor drives two 1500-volt, direct current generators connected permanently in series, thus supplying 3000-volt current for the locomotives.



ELECTRIC TRAINS AT THE ENTRANCE TO SILVER BOW CANYON ON THE CHICAGO, MILWAUKEE & ST. PAUL AND THE BUTTE, ANACONDA & PACIFIC RAILWAYS OPERATING AT 3000 VOLTS AND 2400 VOLTS DIRECT CURRENT



Two Thousand Kilowatt Motor-Generator Sets in Morel Substation

The fields of both the synchronous motors and the direct current generators are separately excited by small direct current generators direct connected to each end of the motor-generator shafts.

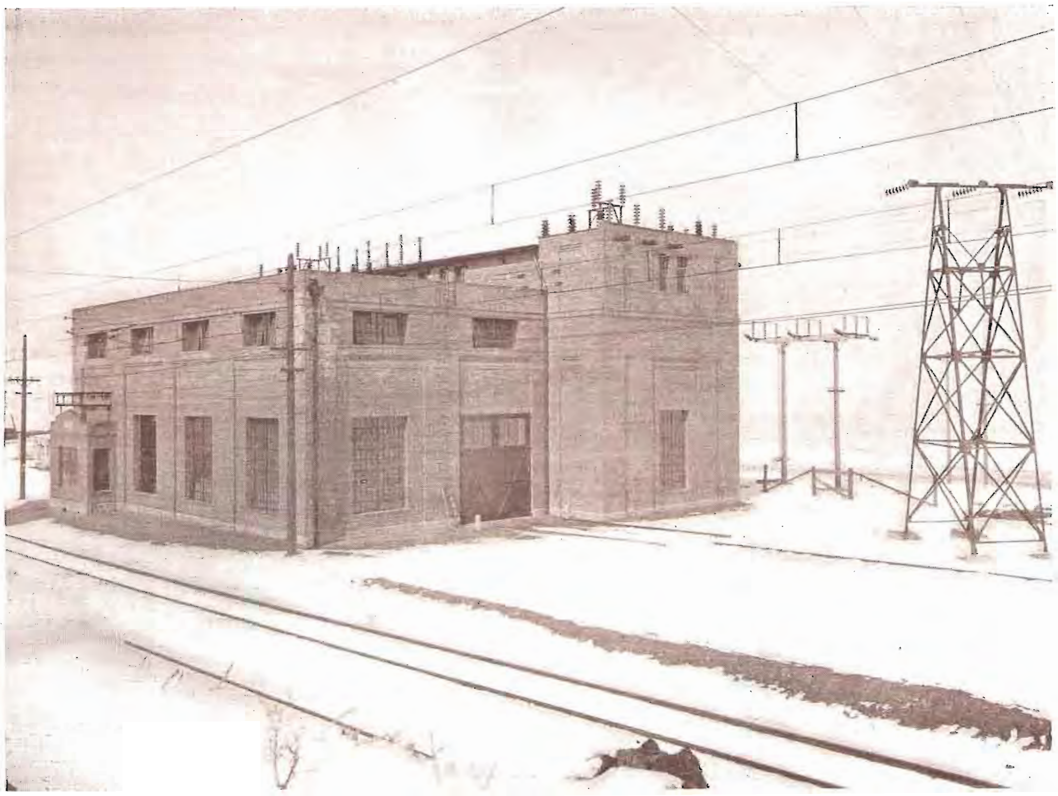
Overhead Construction

The overhead construction is of the modified flexible catenary type designed by the General Electric Company and installed under the direction of the Railway Company's engineers. With this quite novel but remarkably successful construction, the current is collected in both high speed passenger service and heavy freight service without any sparking. As may be seen from the illustrations, the construction comprises two 4/0 copper wires flexibly suspended side by side from the same steel messenger by independent hangers alternately connected to each wire. Bracket construction is used wherever the track alignment will permit, and cross span construction on passing tracks and in the switching yards. All of this work is supported on 40-foot wooden poles suitably guyed and spaced.

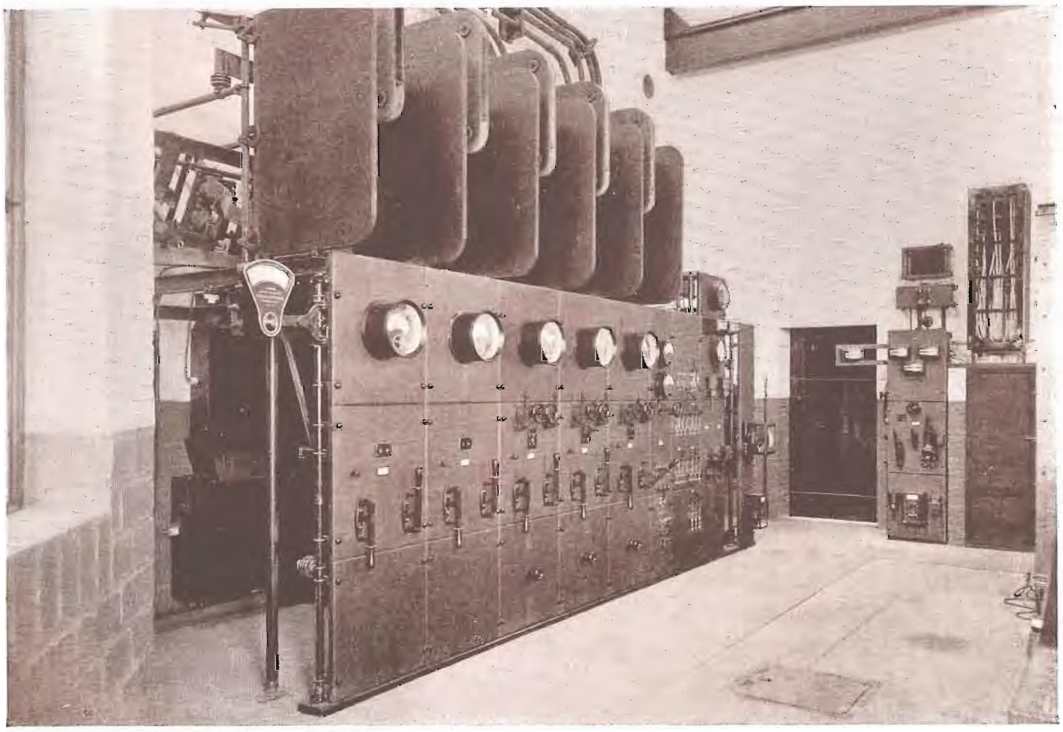
Cost

Electric locomotion has been adopted by the Chicago, Milwaukee & St. Paul Railway as "a newer, better foundation on which builders shall rear the structure of railroading to undreamed-of efficiency and comfort." The enterprise has been undertaken with the expectation of effecting a sufficient reduction in the cost of operation to return an attractive percentage on the investment required, as well as to benefit by all the operating advantages of electric locomotives. According to statements made by the railroad officials, about $12,000,000 will be expended, and with the work more than half completed there is every reason to believe that the cost of construction will come inside the estimates.

Janney Substation



Switchboard Piedmont Substation



Trolley Construction Over Nine Tracks in Deer Lodge Yards

Advantages of Electrification

Summary

Marked reduction in cost of electricity as compared with cost of coal.
Reduction in maintenance cost of locomotives.
Elimination of delays due to coaling, taking water, oil, etc.
Elimination of delays due to natural causes, such as freezing of locomotives, loss of steam in cold weather, bucking snow drifts.
Elimination of non-revenue trains hauling coal and water for steam locomotives.
Increased tonnage per train.
Increased train speed on grades.
Greater reliability and certainty of maintaining schedules.
Reduction in train crew hours per ton mile.
Reduction in damage to rolling stock due to rough handling by steam engines.
Greatly increased safety of operation on grades due to regenerative braking.
Saving in power and reduction in wheel and track wear by use of regenerative braking.
Improvement of tunnel conditions due to smoke and gas, absence of smoke and cinders which obscure scenic attractions, uniform speed and absence of grinding brake shoes on grades, all of which accrue to the benefit of the traveler on the transcontinental passenger trains.

Railway Company's 100,000-Volt Transmission Line

Condensed Technical Data

Transmission Lines

The standard transmission line consists of 45- and 50-foot wood poles with two cross arms carrying 100,000-volt lines on suspension type insulators and also an uninsulated ground wire. There are a number of modifications of this construction on curves, at corner points, substation entrances, etc.

Location and Equipment of the Fourteen Substations

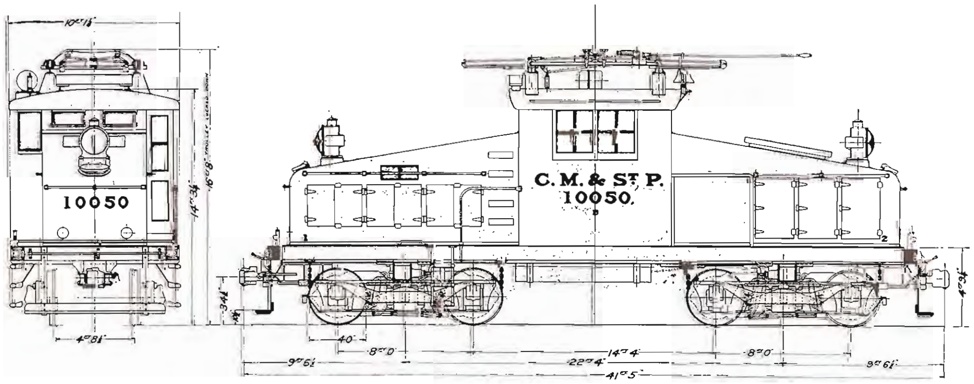
Station	Miles from Harlowton	No. and Size of Units in Kilowatts	Substation Capacity in Kilowatts
Two Dot	12	2–2000	4000
Summit	45.6	2–2000	4000
Josephine	75.8	2–2000	4000
Eustis	105.8	2–2000	4000
Piedmont	148.5	3–1500	4500
Janney	175.9	3–1500	4500
Morel	209.3	2–2000	4000
Gold Creek	244.9	2–2000	4000
Ravenna	277.6	2–2000	4000
Primrose	315.4	2–2000	4000
Tarkio	352	2–2000	4000
Drexel	390.1	2–2000	4000
East Portal	413.9	3–2000	6000
Avery	437.6	3–1500	4500
		32	59,500

Main Line Freight Locomotives

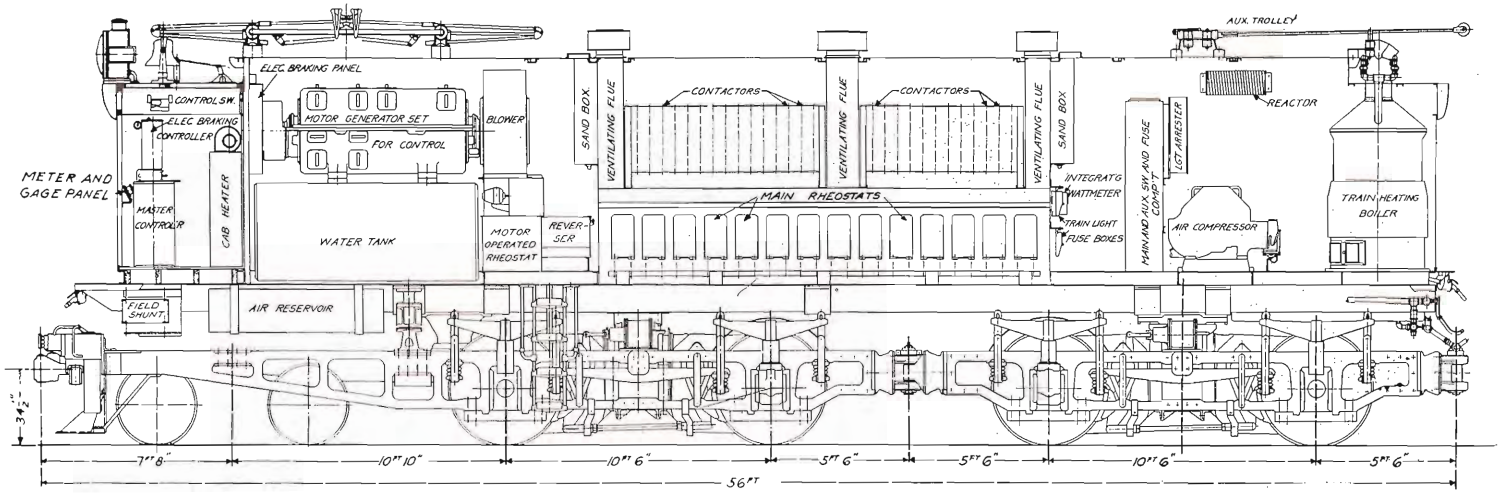
Type of locomotive	3000 volts d-c.
Length overall	112 ft.
Total wheel base	102 ft. 8 in.
Rigid wheel base	10 ft. 6 in.
Total weight	564,000 lb.
Weight on drivers	448,000 lb.
Weight per driving axle	56,000 lb.
Weight per guiding axle	29,000 lb.
Diameter of driving wheel	52 in.
Diameter of guiding wheel	36 in.
Number of driving motors	8
Total output (continuous rating)	3000 h.p.
Total output (1 hour rating)	3440 h.p.
Tractive effort (continuous rating)	71,000 lb.
Per cent of weight on drivers (trac. coef.)	15.83
Speed at this tractive effort at 3000 volts	15.75 m.p.h.
Tractive effort (1 hour rating)	85,000 lb.
Per cent of weight upon drivers (trac. coef.)	19
Speed at this tractive effort at 3000 volts	15.25 m.p.h.
Tractive effort available for starting 30% coef.	136,000 lb.

Switching Locomotives

Length inside knuckles	41 ft. 5 in.
Height over cab	14 ft. 3 in.
Height—trolley down	16 ft. 8 in.
Width overall	10 ft. 1 in.
Total wheel base	30 ft. 4 in.
Rigid wheel base	8 ft.
Diameter of wheels	40 in.
Weight—locomotive complete	140,000 lb.
Weight per driving axle	35,000 lb.
One hour rating of locomotive	542 h.p.
Tractive effort at one hour rating	18,400 lb.
Speed at this rating	12 m.p.h.
Continuous tractive effort	13,480 lb.
Speed at continuous rating	13.2 m.p.h.
Tractive effort 30%	42,000 lb.

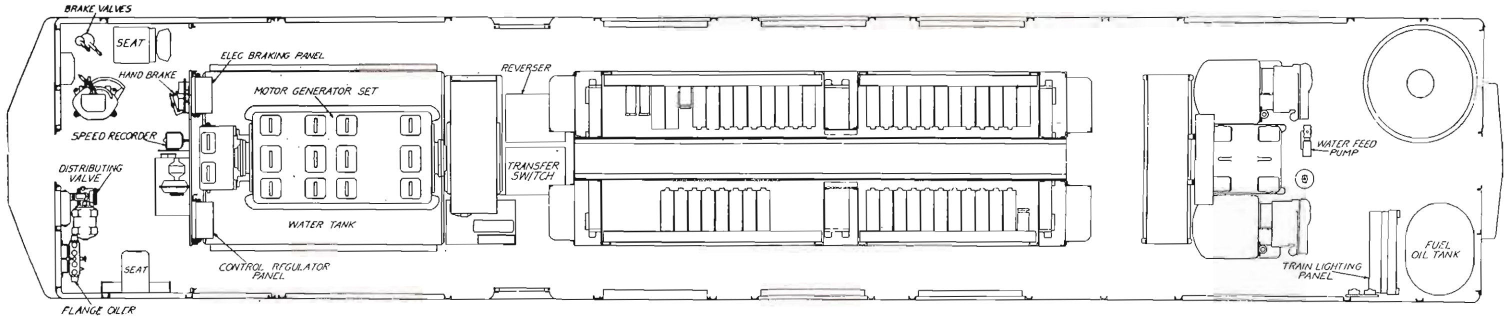


Dimension Outline of 70-ton Switching Locomotive



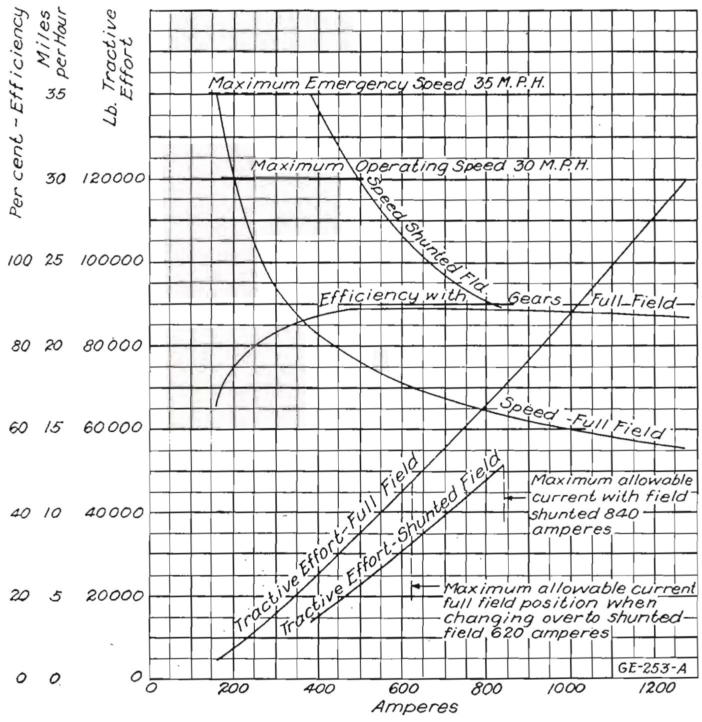
ELEVATION OF HALF LOCOMOTIVE UNIT SHOWING ARRANGEMENT OF APPARATUS

(Train heating equipment omitted on freight locomotives)

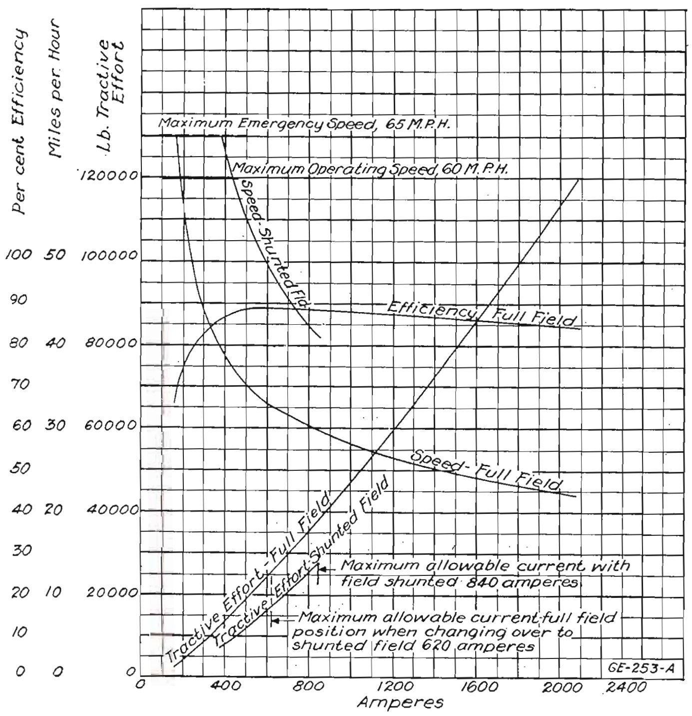


PLAN OF HALF LOCOMOTIVE UNIT SHOWING ARRANGEMENT OF APPARATUS

(Train heating equipment omitted on freight locomotives)

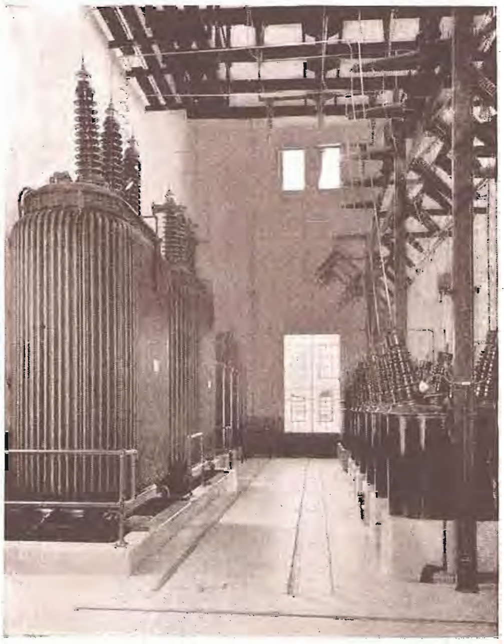


Charac-
teristic
Curves of
Main Line
Freight
Locomotives

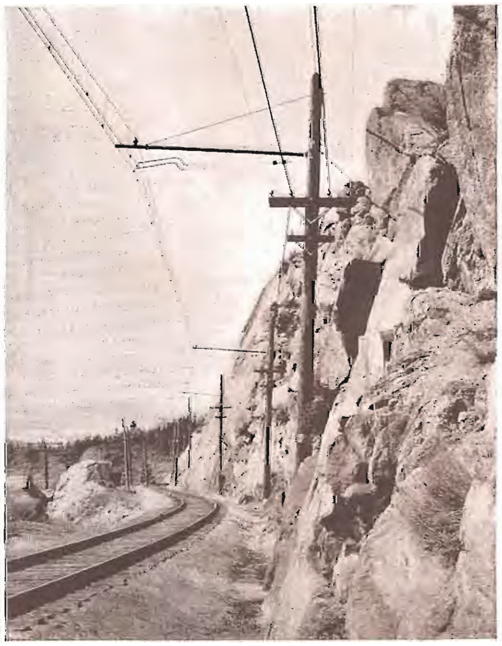


Charac-
teristic
Curves of
Main Line
Passenger
Locomotives

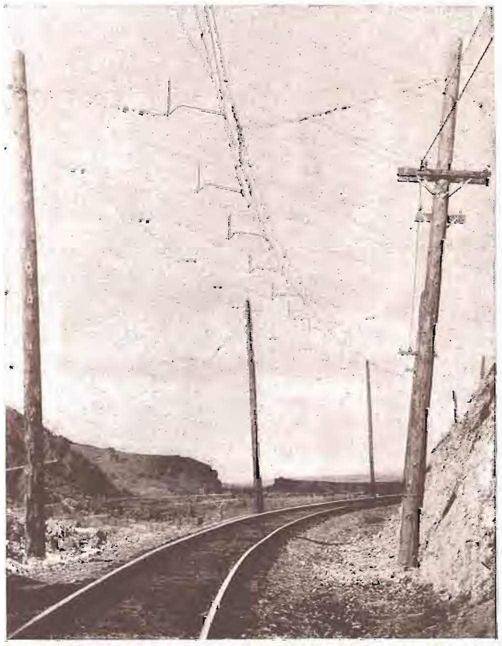
OVERHEAD CONSTRUCTION ON TANGENT TRACK



TRANSFORMERS AND OIL SWITCHES MOREL SUBSTATION



BRACKET CONSTRUCTION ON LIGHT CURVES



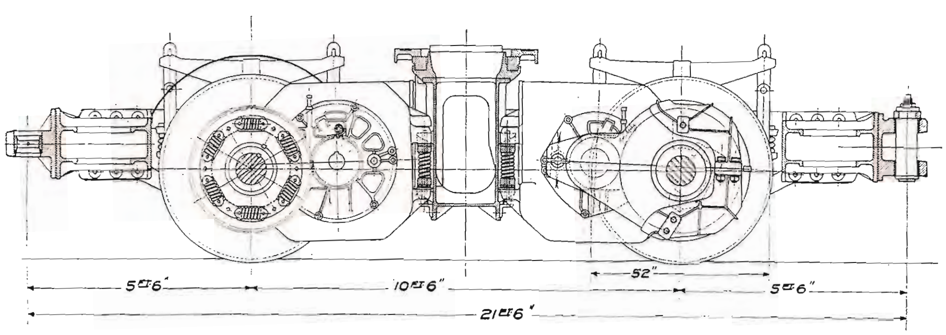
OVERHEAD CONSTRUCTION AT TEN DEGREE CURVE

Overhead Work at Janney Showing Double Track Curve Construction

Overhead Construction

A 500,000 c.m. feeder is installed the entire length of the electrification and a supplementary feeder on heavy grades. The feeder is tapped to the trolley wire at every seventh pole, or approximately every 1000 feet. On top of the poles is carried a supplementary 4/0 negative feeder which is tapped to the middle point of every second reactance bond. These bonds are used for insulating the 60-cycle signal circuits and are installed at points averaging from 5000 to 6000 feet apart. Each track is bonded with a 250,000 c.m. bond on each joint and double bonded on the heavier grades.

The passenger and freight locomotives are identical, with the exception of gear ratio and the addition of an oil-fired steam boiler in each half of the passenger locomotives for heating the trailing coaches. The two boilers are capable of evaporating 4000 pounds of water per hour and this equipment with tanks for oil and water bring the weight of the locomotive up to approximately 300 tons. The interchangeability of all electrical and mechanical parts of the locomotives is considered of great importance from the standpoint of operation and maintenance.



Details of Main Locomotive Truck Showing Spring Gear and Spring Nose Suspension

Hydro-Electric Power Station at Great Falls on the Missouri River

Four 10,000 Kv-a Waterwheel-Driven Generators in Great Falls Power Station

Electric Power Plants of the Montana Power Co.

Completed Hydro-Electric Plants

		Installed Capacity K.W.
Great Falls, on Missouri River		60,000
Rainbow Falls, on Missouri River near Great Falls, completed in 1910		27,000
Black Eagle Falls, on Missouri River near Great Falls, reconstructed in 1913		3,000
Black Eagle Falls, hydraulic power, 8,000 h.p.		
Hauser Lake, on Missouri River, northeast of Helena, completed 1911		18,000
Canyon Ferry, on Missouri River, northeast of Helena, completed in 1898 and enlarged in 1901		7,500
Madison No. 1, on Madison River, 60 miles southeast of Butte, completed in 1901 and 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 Yellowstone River, completed in 1906 and enlarged in 1908		1,500
Billings No. 1, on Yellowstone River, completed in 1907		1,080
Lewistown, on Spring Creek, completed in 1906 and remodelled in 1913		450
Thompson Falls, on Clark's Fork of Columbia River		20,000
		153,530
Steam Plants		
Butte, completed in 1907	5,000	
Billings, completed in 1906	560	
Conrad, completed in 1910	110	
Phoenix, in Butte, completed in 1895	250	5,920
Total		159,450

Hydro-Electric Powers in Course of Development and Definitely Projected

	Capacity K.W.
Thompson Falls, on Clark's Fork of Columbia River, additional units to be installed in 1917	10,000
Holter, on Missouri River near Helena, under construction, to be completed in 1917	40,000
Total	50,000

Hydro-Electric Power Sites Undeveloped

Site "C" at Great Falls, on Missouri River, between Rainbow and Great Falls	28,500
Below Great Falls, on Missouri River	28,500
On Missouri River about 30 miles northwest of Missoula	13,500
Madison No. 3, on Madison River	18,500
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
Total	121,500

SUMMARY

Completed hydro-electric and steam plants	159,450
Hydro-electric powers in course of development	50,000
Hydro-electric power sites undeveloped	121,500
Total	330,950

SUMMARY OF TRANSMISSION LINES IN SERVICE JANUARY 1, 1916

Steel tower lines, 100,000 volts	305 miles
Steel tower lines, 50,000 volts	35 miles
Pole lines, pin type, 11,000 to 60,000 volts	635 miles
Pole lines, suspension insulator type, 50,000 to 100,000 volts	512 miles
Bridge type, 100,000 volts	341 miles
Total	1,828 miles

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.

Type of Mallet Engine Replaced by Electric Locomotives