EXHIBIT B.

NEW YORK CENTRAL RAILROAD ELECTRIFICATION, NEW YORK TO HARLEM.

By MR. C. E. QUEREAU, Superintendent Electrical Equipment.

The electrification of the New York Central in and near New York City was started because of the action of the New York State Legislature in 1903, forbidding the use of steam locomotives south of the Harlem River after July 1, 1908. This was because the steam and smoke of the steam locomotives so filled the two-mile Park Avenue tunnel just north of the terminal that it was extremely difficult, frequently impossible, to determine the location of trains. This made their operation dangerous.

This condition was aggravated by the increasing number of trains, due to a growing passenger business. This fact also made an increase in terminal facilities and a new station necessary. By the use of electricity the capacity of the terminal could be doubled by having station platforms and tracks on two levels, a design impossible with steam locomotives because of the confinement of the steam and smoke. The use of electricity also permitted the erection of revenue producing buildings over the upper level, made possible the connection of the streets from Forty-fifth to Fifty-sixth, inclusive, and the continuation of Park Avenue 140 ft. wide within the same limits, thus connecting two sections of the city which had previously been separated for three-quarters of a mile by the steam operated terminal. The connection of the streets running east and west materially decreased the traffic congestion on Forty-second Street.

A direct current, rather than alternating current, system was adopted because of insufficient practical experience with the alternating current for a trunk line problem requiring the highest possible reliability of service, restricted overhead clearance in the Park Avenue tunnel, which prevented the use of overhead conductors, and legal obstacles to the use of high voltage overhead trolley lines within New York City.

The use of electric locomotives for handling trains made up of cars which must run over lines not electrified was self evident. While it was possible to handle by locomotives the suburban trains which would not run farther than the electric zone, it was decided to use multiple unit cars for suburban service. The use of cars equipped with motors and other necessary electric apparatus very much reduces switching at terminals, eliminates movements to and from engine houses, and for these reasons very materially reduces congestion at terminals. Practical experience so emphasized the importance of having each multiple unit car equipped with power that 55 of the original purchase of 180 cars, which were used as trailers, were subsequently equipped with motors, so that at present all the multiple unit cars are motor cars.

Because of the very great importance of reliable service it was decided to build two power plants, each with a capacity sufficient to furnish current for the entire electrified zone, duplicate transmission lines over the territory most essential, and storage batteries with sufficient capacity to operate the electric division for a period which the experience of others had shown might occur. As the original plans provided only for passenger service, the duplicate power houses and transmission lines will be needed when freight is handled electrically over the electric division.

Electric operation was begun on the following dates: First scheduled multiple unit trains, December 11, 1906. First scheduled electric locomotive trains, February 13, 1907. First switching service, April 14, 1907. All scheduled trains, July 1, 1907.

This operation was begun with 35 locomotives and 180 multiple unit cars, of which 55 were trailers which were subsequently equipped with motors. At present there are 73 locomotives and 241 motor cars.

The operating service obtained from this equipment has been more reliable, with fewer delays, than was obtained from the steam locomotives which were displaced, and very satisfactory indeed, conditions in the tunnel included.

The following table shows the record of train detentions due to failure of the equipment for the year 1918 for electric operation, and the year 1908 for steam. All detentions are included:

ELECTRIC OPERATION, 1918.

No. Detentions.	All Locomotives. Miles Run.	Miles per Detention.
37	1 854 700	50 127

M. U. CARS.

71	5 926 301	83 469

STEAM OPERATION, 1908.
Hudson Passenger Division.

664	4 014 980	6 045

The inspection, repairs and maintenance of the electric equipment of cars and locomotives has proven to be a comparatively simple and inexpensive process, costing less than that of steam equipment:

TABLE II.— INSPECTION AND REPAIRS OF ELECTRIC LOCOMOTIVES.

Year.	Cost per 1 000 Miles.		
	Labor.	Material.	Total.
1912...........	$18.88	$14.60	$33.22
1913...........	19.82	14.54	34.36
1914...........	21.55	21.34	42.89
1915...........	19.01	13.79	32.80

Table III gives corresponding figures for the inspection and repairs of the multiple unit cars:

TABLE III.— INSPECTION AND REPAIRS OF MULTIPLE UNIT CARS.

1912...........	$11.34	$ 7.40	$18.74
1913...........	10.09	7.47	17.56
1914...........	10.13	9.19	19.32
1915...........	12.56	12.25	24.81

These figures, as well as those for the locomotives, are fair averages of cost for the twelve years of electric operation until the year 1918, when wages were appreciably increased by the Government.

In this connection it should not be forgotten that the figures given do not include fixed charges, which must be included in arriving at the comparative cost of steam and electric operation.

Experience has shown that it requires less electric locomotives than steam for the same amount of work. This fact is due to several electric characteristics, among them two which are very evident. One of these is the fact that no time is lost by the electric equipment in having fires cleaned and supplies of coal and water furnished. Again, the electric locomotives take the slack and handle their loads with more snap than the steam engines. The following, Table IV, gives the number of steam and electric locomotives required in several districts:

TABLE IV.— ENGINES USED — HUDSON DIVISION.

Steam.	Electric.
53 engines and 78 coaches...........	17 engines and 97 multiple unit cars.

HARLEM DIVISION.

41 engines and 95 coaches...........	11 engines and 116 multiple unit cars.

SWITCHING CREWS.

At G. C. T..........	16 crews.	11 engines.	11 crews.	5 engines.
At M. O.............	20 crews.	14 engines.	12 crews.	6 engines.
Total.........	36 crews.	25 engines.	23 crews.	11 engines.
Shop Crews...........	26 crews.	20 engines.	18 crews.	12 engines.
Total.........	62 crews.	61 engines.	41 crews.	23 engines.

Table IV shows a decided decrease, not only in the number of locomotives used because of electric operation, but, as well, in the number of engine crews.

There is nothing unusual about the design or equipment of the multiple unit cars.

The electric locomotives have bipolar gearless motors which are unusual in locomotive design. These are cheaper in maintenance than the geared type, and the engines ride very smoothly. There is a belief that these engines are hard on the track, kinking the rails and, in extreme cases, somewhat displacing them. Twelve years' experience in service disproves this, and the Division Engineer states this is not true. If the lateral clearance is kept within reasonable limits, about three-fourths that allowed on steam engines, there are no symptoms of nosing. It is not at all difficult to do this, as the cost of repairs demonstrates.

One factor in connection with electrification is worth more than a passing notice. I refer to the under-running third rail, which is of decided service in the case of heavy snowfalls which with an over-running third rail considerably hamper and very widely prevent the collection of electric propulsion power from the third rail, resulting in loss of power and very unsatisfactory train operation, while the under-running third rail proceeds with practically no disturbance of normal operation. For the twelve years of electric operation practically every winter has demonstrated the very decided advantage of this detail.

A study of the large table gives the following interesting information:

There are fourteen roads which have electrified divisions and eleven of these have a tunnel in them.

There are 925.37 miles of route and 1906.05 miles of track electrified.

As to the current used, there are four roads using 600-volt D. C., two using 2400-volt D. C. and one using 3000-volt D. C., a total of seven using direct current.

Of those roads using A. C., there are four using a voltage of 11,000.

There is one road using three-phase current with a voltage of 6600, and one road using split phase current of 11,000 volts.

On five roads third rail is used and eleven roads have trolley wires.

NAME OF ROAD AND SECTION ELECTRIFIED.	GENERAL. Character of Service.	Specific Cause of Electrification.	Began Electrical Operation.	PERMA... Length of Route Miles.	...NG ST... ...S. ...ur ... H. P.
Baltimore & Ohio, Baltimore, Md. Baltimore Tunnels................	Heavy Pass.& Freight	Tunnel & Terminal...	1895	3.6	720 800 1 120
New York Central & Hudson River R. R., New York to Harmon........	Heavy Pass.........	Terminal...........	1906	53.6	2 200 2 340 2 640 2 640
New York, New Haven & Hartford R. R., New York to New Haven....	Heavy Pass.& Freight	Terminal Gen. Econ..	1908	74	1 410 1 510 1 700 1 700 1 700 750 2 550
Grand Trunk Ry. Co., St. Clair Tunnel Co., Port Huron, Mich., St. Clair Tunnel...........................	Heavy Pass.& Freight	Tunnel.............	1908	2.5	720
Great Northern R. R., Cascade Tunnel, Washington......................	Heavy Pass.& Freight	Tunnel.............	1909	4	1 50
Michigan Central, Detroit River Tunnel, Detroit, Mich....................	Heavy Pass.& Freight	Tunnel & Terminal...	1910	6.25	1 12 1 12
Boston & Maine R. R., North Adams, Mass., Hoosac Tunnel............	Heavy Pass.& Freight	Tunnel.............	1911	7.92	1 51
Penn. Tunnel & Terminal R. R., P. R. R. into New York City...............	Heavy Pass.........	Tunnel & Terminal..	1910	15	2 50 2 50
Butte, Anaconda & Pacific R. R., Butte-Anaconda, Mont..................	Heavy Frgt. & Pass..	Gen. Econ..........	1913	30	1 28 1 28
Norfolk & Western R. R., Bluefield-Elkhorn, W. Va...................	Heavy Frgt. & Pass..	Tunnel, Heavy Grade	1915	30	1 6
Canadian Northern, Montreal, Canada.	Heavy Pass.........	Tunnel & Terminal..	1919	9	1 2
Chicago, Milwaukee & St. Paul Ry., Montana Electrification............	Heavy Pass.& Freight	Gen. Econ..........	1915	437	3 4 3 4 4 2
Chicago, Milwaukee & St. Paul Ry., Cascade Electrification.............	Heavy Pass.& Freight	Gen. Econ..........	1919	217	3 2
Pennsylvania R. R., Paoli and Chestnut Hill Div.........................	Suburban Pass......	Terminal...........	1915	30	1 ...
New York Connecting Railroad.......	Heavy Frgt. & Pass..	Connecting Terminals	1918	5.5	ro

a Furnishes power to Long Island R. R. Co., 60 cycle power for lighting and au...
b These transformer substations are of the outdoor type, one being located near e... double purpose of allowing a higher transmission voltage and reducing th...
c Momentary capacity 3 times normal.
d Mechanical parts built by Penn. R. R.
e Two running speeds—first using 4 poles, second using 8-pole connection on mo...
f Full field data on first line; tapped field data on second line.
g Including 30 motor cars of New York, Westchester & Boston.

EXHIBIT C.

BRIEF HISTORY OF NEW YORK, NEW HAVEN & HARTFORD RAILROAD ELECTRIC ROLLING STOCK.

Written for Committee on Design, Maintenance and Operation of Electric Rolling Stock.

By Mr. W. L. Bean, Mechanical Assistant.

The present electric rolling equipment of the New Haven Railroad on its principal electric division, namely, New York to New Haven, consists of 104 electric locomotives, 27 multiple unit cars and 52 trailer cars. All operate at 11,000 volts, single-phase, alternating current. Some are arranged to operate at 660 volts direct current, also, in order to enter New York City over the tracks of the New York Central Railroad or Pennsylvania.

Operation was started in June, 1908, as far as Stamford, Connecticut, 36 miles from Grand Central Terminal; then in 1914 extended to New Haven, 72 miles from Grand Central Terminal. This was the first large trunk line electrification of the world to extensively use locomotives for all classes of service; that is, for fast and local passenger, freight and switcher. Although designed at a time when information on the requirements of an alternating current, high voltage, high speed, heavy train capacity locomotive was very meager, the locomotives are today comparable with those designed in the light of all the experience gathered in the last thirteen years. This is the more noteworthy when it is remembered that most electrical apparatus becomes obsolete often before sufficient time has elapsed to get it erected and going. In general design the last locomotives purchased in 1910 are the same as those purchased in 1919, most of the principal improvements of the 1919 lot being in the auxiliary apparatus and the control apparatus. The general features are the same as those of the locomotives designed today, which extended service and experiment have proved best. Some of the experimenting of the New Haven was carried out by building one locomotive of each type. The locomotives of the New Haven may be divided below into two groups, (I) the standard types, (II) the experimental types.

I. Standard.

		Wheel Arrangement.
1—Gearless motors for fast passenger service. First type built. Now obsolete for single phase	01-041	2-4-4-2
2—Geared passenger, freight and switcher locomotives	Frt. 076-0111 Sw. 0200-0214 Pass. 0300-0304	2-4-4-2 0-4-4-0 2-6-2-2-6-2

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II. Experimental.

		Wheel Arrangement
Geared 3-truck fast freight or passenger locomotive	069	2-4-4-2
Geared 2-truck fast freight or passenger locomotive	071-2	2-4-4-2
Geared side rod freight locomotive	068	4-4-4-4
Side rod locomotive	070	2-4-4-2

The above list contains locomotives which represent every mechanical type of drive put forth to date, either in this country or in Europe, as the best solution for transmitting the torque of the motors to tractive effort at the rim of the driving wheels.

The type that proved best for passenger and freight service is represented by New Haven locomotives 076-0111 and 0300-0304. This is a geared type with twin motors, that is, two motors bolted together and driving one pair of wheels through helical springs. A lot of ten locomotives of this same mechanical type has just been made (January, 1920) for the Chicago, Milwaukee & St. Paul. This type of locomotive is now the standard for both freight and passenger service on the New Haven. For switcher service the same general type is standard, except that a single motor and an 0-4-4-0 wheel arrangement is used to better adapt the locomotive for switcher service. Increased switcher power will be obtained by multiple operation of units, for this gives greatest flexibility in assignment to service. From the above it will be seen that a high degree of standardization has been obtained since three different classes of service are handled with but two types of motor and one type of drive. The interchangeability of parts made possible reduces the number of spare parts necessary to be carried in the storehouse.

A corresponding standardization of the auxiliary apparatus and control apparatus has brought the standard designs of the three classes of locomotives as close to each other as the economical distribution of material will permit to best handle the differences in capacity necessary to meet the different service requirements. A few of the major instances are as follows:

1. Standard motor for freight and passenger service.
2. A universal blower motor applicable to all classes.
3. A universal compressor and compressor motor.
4. Standard pantagraph.
5. Standard line switch.
6. Many detail parts of control apparatus and switch groups not interchangeable as a whole.

The standardization has been accomplished by coöperation with manufacturer, the most noteworthy point being that practically all improvements found necessary to meet the service were effected by development of details rather than by changes in fundamental design.

Though the gearless locomotive of the 2-4-4-2 type (01-041) has given very good service for the past twelve years in both local and fast express service, it is now replaced by the geared locomotive of the 0300-0304 type. The other types listed under "experimental" have not proved successful and will not be duplicated on the "New Haven." The type represented by locomotive 068, with a geared side rod drive and a 4-4-4-0 wheel arrangement, has been used for polyphase motor drive to obtain certain advantages possible with such a combination. These advantages are not available with single-phase commutator motors. As for the side rod type, represented by locomotive 070, wheel arrangement 2-4-4-2, no new standard gage locomotives of this type have been designed in recent years in this country. For narrow gage roads, where a large motor would not fit between wheels, the type has its advantages; but for main line, standard gage, high speed, heavy tonnage service it has not proved successful on the "New Haven."

The multiple unit cars may be divided into two groups, those operating on 11,000 volts single-phase only and those operating on both single-phase and 660 volts direct current. There are six motor cars of the former and twenty-one (21) of the latter. Each motor car will pull two trailers. There are fifty-two (52) trailer cars. Of the twenty-seven (27) motor cars but two are now equipped with automatic control. Originally, eight cars came equipped with automatic control. This was removed and cars changed to hand control. The six cars built for alternating current only have straight alternating current motors. The control on these is arranged to change the connections of the motor as the speed varies to obtain best commutation. Four of the first motor cars, 4020-4023, were equipped with a flexible drive similar to that used on the gearless locomotives, 01-041. Fourteen later ones came with the helical spring drive. The last four cars were built with flexible gears. All the motor cars were later changed to flexible gears. The flexible gear gives a much easier riding car, a simpler design, and one easier to maintain.

Just as on the locomotive, every effort has been made to reduce the number of parts to a minimum by standardization so that some of the control and auxiliary apparatus is interchangeable with that of the locomotive.

The development has been toward replacing existing apparatus with that of larger capacity so an increased tonnage rating might be secured or a greater daily mileage. The installation of larger units meant a rearrangement of apparatus, so that usually a large difference in appearance results, due to but a small modification in design.

All New Haven locomotives and cars collect current from an overhead trolley wire by a sliding pantagraph trolley. This method is today recognized as the established standard for trunk line railroads. While a third-rail shoe is provided, it is used only for operation over the 660-volt direct current zones of the New York Central and Pennsylvania Railroads into New York City. The necessity of operating at both 11,000 volts alternating current and 660 volts direct current complicates the locomotives a little, as well as requiring some additional apparatus otherwise not needed.

Just as the principal features of the twin motor-quill spring drive have proved satisfactory and are to be found in the latest locomotives, so has most of the other main and control apparatus remained the same, the chief improvements being made in materials and detail designs.

EXHIBIT D.

GREAT NORTHERN RAILROAD ELECTRIFICATION, CASCADE TUNNEL.

By Mr. Wm. Kelly, General Superintendent Motive Power.

In the year 1908 construction was begun of power plant, transmission line, sub-station, trolley system for Cascade Tunnel and Tye yards, and through the Cascade Tunnel, and four electric locomotives were purchased. Work was completed late in the year 1909 and operation begun, and this operation has been successful ever since. The power plant is located at a point thirty miles east of Cascade Tunnel on the Wenatchee River, and consists of three water-wheel driven generators, each of a horsepower capacity of 4000, a kilowatt capacity of 2000 nominal, generating current at three-phase, 25-cycle, 660 volts. There are also in the station two 125 kw. direct-current generators, used principally for exciting the aforesaid generators. They are also used for crane service in operating the overhead crane in the power room. The power dam is located two and one-quarter miles above the plant, developing a 180-ft. head, and the water is carried from the dam to the power plant down the canyon in a pipe line 8 ft. in diameter built for the greater part of its length of wood staves. It crosses the river on a steel bridge and in a steel pipe line which terminates in a surge tank, being about 200 ft. high, surges being taken care of by an overflow from the tank into the river.

From the generators the current is conducted into a transformer room, where it is fed through a switchboard to three 850-KVA single-phase transformers which step up the voltage from 6600 to 33,000. It is then transmitted parallel to the railroad track to the sub-station at Cascade Tunnel, 30 miles distant.

The sub-station is equipped with three transformers of the same capacity as those in the power plant, and current is stepped down from 33,000 to 6600 volts, where by suitable manual switching devices it is distributed to the trolleys in the Cascade Tunnel yard, Tye yard, and in the tunnel itself. The trolley system consists of two trolley wires over each track, the voltage between the trolley wires being 6600 and the voltage between either wire and the rail being the same, 6600. Th current is conducted into the locomotive by two regular street-car trolley poles and wheels located at each end of each locomotive. It is fed into two three-phase transformers and converted to 500 volts, which is the voltage of the driving motors and also of the auxiliary motors on these locomotives. All motors, including the driving motors, are of the three-phase induction type, the traction motors being of the slip-ring type, and control is through resistance same as any ordinary slip-ring stationary motor. The control is of the Sprague multiple type, the engineer's controller handling only very small currents, these being control currents which actuate the magnets of the Sprague multiple system. The auxiliary motors are three in number, two being used to drive air compressors for the air brakes and one being used to drive a fan for the ventilation of the transformers and the traction motors.

The locomotives weigh 115 tons each. All driving wheels are traction wheels, each motor being coupled to its axle in identically the same manner as is done with street-car motors, being geared in single threads. The motor pinion has 19 teeth, 1¾ in., and the driving gear mounted on the axle has 81 teeth. The motor shaft has a pinion on each end, each driving its gear mounted on the axle. An interesting feature is that there are no cushion springs in the gear in order to equalize the tooth pressure, as has been considered necessary on almost all heavy locomotives; and we find that there is an equal amount of wear on both pinions, the tooth pressures seem to be uniform, and the wear up to date has been almost negligible on all of these gears and pinions. The driving wheel diameter is 60 in. over the tire. The rated capacity of each traction motor is 250 h-p., but each is capable of an overload of 50 per cent for the short periods that we are able to use them continuously. There being four motors, the rated capacity of each locomotive is 1000 h-p. and this develops a tractive effort of 25,000 lb. per locomotive. The overload capacity is such that a tractive effort of 37,500 lb. is easily developed. The speed of the driving motors is constant, being of the induction type, and drives the locomotive at a constant speed of 15 miles per hour. The reason for this constant speed was that this was supposed to be a link in a larger system in which the principle of regeneration on descending grades is very desirable, and it was at the time the only method of regeneration which had been developed. The results of this regeneration were such that this feature was shown to be very desirable for all electrification, especially of mountain grades, and since that time the General Electric Co. has developed the regenerating locomotive, using the series direct-current motor, something which up until a few years ago was considered almost impossible of accomplishment. Our mileage, however, is so short, being only about three and one-half miles of electrified main line, that this feature is of practically no value to us.

For each steam locomotive we were using previously as a helper we substituted an electric locomotive, of which there are four. It was a case of necessity, going to electrification, as the conditions in the tunnel were unbearable when using steam locomotives. Furthermore, considerable delay took place in waiting for the tunnel to clear. The atmospheric conditions some days were such that it would clear in one hour and again it would take several hours. There were many times, however, the conditions were such that the men did not wait for the tunnel to clear and they would proceed, the engineer and fireman using an apparatus known as a respirator. There is a greater regularity of traffic due to the electrification and we have increased the movement materially.

As to maintenance, we have a one-stall locomotive shed at the Cascade Tunnel side of the mountain where periodical inspections are made, and where all repairs are made except turning of tires. When this is necessary each locomotive is taken down to the Delta shops, which are 76 miles from tunnel. A crew of electricians consisting of four men is necessary, yet this same crew could take care of a great deal more equipment if we had it. The following is data on cost of operation:

Repairs per locomotive mile	$ 7.53
Wages	27.39
Lubrication	.20
Supplies	.33
A total of	$35.45

Miles made per pint of cylinder oil, 313. Miles per pint of car oil, 19. Average gross tons per engine mile, 345. It is to be noted that every train has three electric locomotives, consequently the tonnage per train is three times this, or 1035 tons. Total passenger car miles, 48,096. Total number of tons one mile is 8,461,770. This data applies to the year 1918.

EXHIBIT F.

ELECTRIC OPERATION ON THE BUTTE, ANACONDA & PACIFIC RAILWAY.

In the beginning seventeen electric locomotives took the place of twenty-eight steam engines, effecting a substantial reduction in wages of train crews, in equipment expenses and in shop employees.

F. W. Bellinger,
Electrical Superintendent.

ELECTRIC OPERATION ON THE BUTTE, ANACONDA & PACIFIC RAILWAY.

The Butte, Anaconda & Pacific Railway was built in the year 1892, principally for transfer service between the ore mines in Butte and the Washoe Smelter at Anaconda. The tracks connecting these two cities are approximately twenty-six miles long, but the yards and sidings included in the present electrification bring the total mileage up to 120.

Until the Butte, Anaconda & Pacific Railway Company decided upon the electrification of its line, for economical reasons alone, it is questionable if any such steps had been made by steam line railroads. The electrification of various steam roads has been for the purpose of obviating some special condition, such as smoke nuisances in tunnels or cities, congested terminals, or to accomplish some special work which a steam engine could not be used to do.

Work on the electrification began in the spring of 1912 and the first electric locomotive was run experimentally at Anaconda on May 4, 1913. Two weeks later a double unit electric locomotive took over the work of the regular day crew on the Smelter Hill line. This crew hauls all the ore between the East Anaconda yards, where the trains are broken up into drags for distribution, and the Concentrator yards, the distance being on the order of seven miles.

Regular passenger service between Anaconda and Butte was taken over for electrical operation on October 1, 1913. The distance between these station is 25.7 miles. The schedule is one hour and includes fifteen possible stops, the most of which are made.

On October 10, 1913, a double unit electric locomotive was put in the day freight service between East Anaconda and Rocker, a distance of 20.1 miles. The remainder of this class of freight service was gradually taken over during the months of October and November, thus completing the electrification of the main line.

To show that the management was justified in their choice of 2400 volts, direct current, to meet the unusual conditions on this railway, a few concrete transformations will suffice.

On the Smelter Hill line, a distance of approximately seven miles with a grade of 1.1 per cent, twenty-five ore cars averaging 70 tons each make a trailing load of 1750 tons forming a drag. The round trip is made in about an hour, thus making it possible, avoiding any unusual delays, to make eight round trips per day or a delivery of 200 cars in ten hours. On the other hand, a steam engine handled under favorable conditions sixteen ore cars weighing 70 tons each, or a trailing load of 1120 tons, making it possible to make six round trips in ten hours or a delivery of 96 cars per day. Therefore we have an increase of 108 per cent in this particular service, using the same crew and working the same hours as worked by the steam engine crew.

On our main line freight service between East Anaconda and Rocker, a distance of 20.1 miles, the standard train, westbound, that had been handled was 50 cars aggregating 3500 tons; and the average running time for such a train, where no stops were made, was about one and one-half hours, corresponding to an average speed of approximately 13.4 m. p. h. In the beginning the electric locomotive took only the standard train, making the trip without stops in an hour, corresponding to an average speed of 20 m. p. h. The ruling gradient on the westward trip is 0.3 per cent, and with a 55-car train the steam engine made approximately 7 m. p. h. The electric locomotive with similar trains made 16 m. p. h. on the same grade. The weight of the trains on this run has been gradually increased up to 65 loaded ore cars averaging about 71 tons each, making the trailing load 4620 tons. Adding 160 tons for the locomotives and 20 tons for the caboose makes a gross train weight of approximately 4800 tons.

A comparison of the month of June, 1913, under steam operation with the same month, 1914, under electrical operation shows that with a slight increase in the total tons of ore handled the average tonnage per train was increased from 1761 to 2378, or 35 per cent, thus decreasing the average number of trains per day from 12.5 to 9.3 or 25.6 per cent.

The average time per trip during steam operation was approximately two hours and twenty-five minutes, while with the electric locomotive it was possible to make the trip in one hour and forty-five minutes, showing a decrease of forty minutes or 27.5 per cent.

Tabulated results from a comparison of the delays to passenger trains for the month of June, 1913, under steam operation, with the same month in 1914 under electrical operation, are shown in Table 1. While the month of June is selected at random, the results are considered representative of the general performance. Under delays on account of engine and power failures you will note that there is an increase in the case of the electric engine operation which, as explained below, is due to the fact that power failures occurred.

TABLE I.

Number of Trains.	Meeting Points.	Delays on Account Engine and Power Failures.	Lost Running Time.	Total Delays, All Cases.
	Hr.-Min.	Hr.-Min.	Hr.-Min.	Hr.-Min.
Steam, 1913 272	15–49	0–44	4–13	20–46
Electric, 1914 280	3–54	0–51	0–25	5–10
Decrease 8*	11–55	7*	3–48	15–36

Percentage saving due to electrical operation:

2.94%*	75.66%	15.91%*	90.10%	75.12%

*Increase.

It will be observed that under electrical operation 2.94 per cent more trains were operated with a decrease of 75.66 per cent in time lost at meeting points, 45.45 per cent decrease in time lost because of engine failures (offset by some stoppages due to power failures) and 90.10 per cent decrease in lost running time, with a total decrease of 75.12 per cent in delays of all kinds.

The change effected in the service on the Missoula Gulch line, running between Rocker and Butte Hill Yard, is particularly striking. This line is 4.5 miles long with a ruling gradient of 2.5 per cent. Under steam operation two crews with locomotives of the Mastodon type had been required to handle the service, each averaging six trips per day. In their place a single crew with a double unit electric locomotive performs the work successfully. From 35 to 45 loaded ore cars are taken down from Butte Hill Yard to Rocker and about an equal amount of empties taken up per trip. In addition to the empties, large quantities of timber and mine supplies are delivered over this line.

The trackage in and about the mines runs on many different levels, thus necessitating heavy grades and curves. It is safe to say that in approximately twenty-five miles of electrified track enough tangent track could not be picked out to equal five miles. Thus the overhead system has been built up to meet unusual conditions. The original installation was somewhat experimental so far as the support structure was concerned. Therefore, subsequent to the first year of operation under electrical power, we found that it is possible to make a considerable reduction in the cost of overhead construction, due to a more general use of bracket construction in place of the two pole spans. On curve construction, up to and including four tracks with 4 deg. of curvature, we trim the pull-off points to a substantial backbone. Five tracks or more are trimmed in the usual manner, with the exception that the backbone is done away with and a pole substituted at each pull-off point. This change in construction was found necessary to reduce maintenance costs.

Three linemen are employed to maintain the overhead lines and feeders, with headquarters at Anaconda. One box car with a wood tower is kept for heavy line work and construction jobs. A Federal one and one-half ton truck equipped with car wheels and a Trenton tower gives a quick, light car for all general line work. The Trenton tower, as well as the movable table on top, are generously insulated so that it is possible to work our trolley under all weather conditions.

The average cost of maintenance of overhead system per mile per year for the past four years is $137.57. The year 1918 will give an idea of the proportionate cost for each item considered.

Poles and Fixtures		Feeder.		Trolley.		Bonding.	
Labor.	Material.	Labor.	Material.	Labor.	Material.	Labor.	Material.
$3261.52	$687.46	$554.10	$87.77	$3 889.79	$1 168.86	$1 410.96	$1 980.23

Total of above accounts	$13 040.69
Motor Car M 1	1 119.65
Work Train	2 290.04
Total Maintenance Expense	$16 451.08
Number of miles operated	120.27
Cost per mile per year	$136.78

Recent measurements of our trolley wires give every reason to cause us to believe that the major portion of our overhead wires will last fifteen years. While there are a number of places that will wear out in less time, there are other places which will wear much longer than fifteen years, depending on the frequency of movement and current collected. The greatest wear, as would be expected, comes at rigid points, such as pull-offs and rigid hangers.

As a means of collecting current for the locomotives we have used the roller pantagraph since the beginning. A few changes were necessary in the bearings. One pantagraph is used on each locomotive and a 2400-volt bus line is used where two locomotives are coupled, thus insuring continuous current to both locomotives while passing under wood sectional insulators or in the event of arcing at rigid points.

The current collected is on the order of 400 amperes per engine, and it is our experience that better operating conditions are obtainable from the use of two pantagraphs. Pantagraph rollers give an average life of 20,000 to 40,000 miles. Each roller is mounted on a pair of Hyatt roller bearings which wear out as many as three roller tubes. These bearings are greased twice each week with semi-hard grease. The contact pressure is maintained at approximately 30 lb. and is adjusted by means of a hand spring balance. All adjustments of this kind are made on a special track which is wired but not energized.

Power is furnished by the Montana Power Company, which is comprised of many interconnected developments. The Butte and Anaconda sub-stations which feed the two ends of the railway system are connected by three tie lines on the A. C. side and have no less than five hydro-electric plants feeding directly to these ties.

The advantage of purchasing electric power from this large operating company, instead of developing the required power independently, was readily apparent in the case of the Butte, Anaconda & Pacific Ry. Co. Hence this road was relieved of all first cost of development and transmission of power and all operating expense up to the point of delivery at the two sub-stations. Butte sub-station is equipped with three 1000 kw. motor generator sets, exciter units and switchboard appurtenances, while at Anaconda the sub-station is equipped similarly with the exception of having four 1000 M. G. sets.

A power contract was made which is in accordance with the usual practice, being made to favor as much as possible all ordinary conditions which may arise. On the other hand, the railway company makes every effort to operate their sub-stations at as high a load factor as is possible and at a leading power factor. Under normal operating conditions it is possible to average a 42 per cent load factor. The nature of the haul on this line is such as to make it impossible to dispatch all trains, although good results are generally obtained, even in the switching service, by the coöperation of the yardmasters.

A comparative statement showing the cars handled per day for the months of April, 1917-1918, is as follows:

	Cars.	Average Cars, per Day.
April, 1917	31 282	1 042.7
April, 1918	25 980	866.0

Comparative statement of tonnage handled per day for months of April, 1917 and 1918:

	Total Tons.	Average Tons per Day
April, 1917	1 337 911	44 597
April, 1918	1 137 498	37 916.6

Comparative statement of tonnage hauled per train for months of April, 1917 and 1918:

MAIN LINE.

	Trains East.	Tons.	Average Tons per Train.
April, 1917..................	190	275 327	1 449.09
April, 1918..................	154	240 217	1 559.85
	Trains West.		
April, 1917..................	190	787 634	4 198.07
April, 1918..................	155	716 925	4 625.32

Average Tons per Train East and West.

April, 1917....................................2 797.26

April, 1918....................................3 097.547

While these figures are representative of the average business handled, they are not taken from the best months' performance, and are shown for the purpose of throwing light on the cause for electrifying. In handling the tonnages shown above over a single track line with limited sidings a marked improvement was shown in the number of delays, as well as in overtime to the train crews. A similar saving has been very noticeable in the mechanical department.

It may be of interest to know how we heat our coaches. Each coach heater is of 25 kw. capacity, having a thermostat control, and operating on 2400 volts. The contactor control for each equipment receives a potential of 600 volts from a dynamotor located on the locomotive. Fresh air is introduced into the heater by means of a fan, and after being heated to a temperature of 100° to 105° C. is forced out through longitudinal ducts placed inside the coach. The heater, principally because of high voltage, is located below the floor. Heater and piping are lagged with heat insulating material. Three electrical workers are employed at the machine shop to make such repairs as are necessary on electric locomotives, shop light and power, coach heating and lighting, as well as assisting in the maintenance of block signals and dispatcher's telephone.

Five groups of five lamps in series are used to illuminate each coach. The voltage is 600 and is obtained from the dynamotor. Mazda lamps are used exclusively and the average life is remarkably high.

Twenty-eight electric locomotives weighing 82 tons each and equipped with four G. E. 229 motors with type " M " control handle the major portion of the work. Two steam engines are retained for service on the Georgetown branch and a sand pit job, which are not electrified.

The following figures give an idea of the cost per year for repairs:

	1914	1915	1916	1917	1918	1919
Number electric locomotives	17	18	21	24	28	28
Average locomotive weight, tons	80	....	....	....	....	....
Installation date	1913					
Route miles electrified	30	....	....	....	....	....
Miles single track basis	90	90	114	114	120	122

MAINTENANCE OF ELECTRIC LOCOMOTIVES.

Repairs in dollars	27 811	35 253	49 811	55 846	54 167	35 264
Depreciation in dollars	26 829	....	24 143	36 695	32 707	33 567

ELECTRIC LOCOMOTIVE MILEAGE.

Freight revenue miles	321 946	317 595	505 162	412 509	413 519	226 851
Passenger revenue miles	65 428	87 625	100 290	94 659	80 020	90 805
Switch revenue miles	136 892	161 871	404 356	367 690	324 322	197 838
Mixed and special revenue miles	....	....	616	456	....	....
Total revenue miles	524 266	567 091	1 011 424	875 314	817 861	515 474
Non-revenue miles	....	5 507	2 477	10 796	2 957	1 142
Total locomotive miles	524 266	572 598	1 013 901	886 110	820 808	516 616
Maintenance per locomotive mile in cents. (Not including depreciation)	5.3	6.16	4.91	6.3	6.4	6.8

The above figures will possibly carry more weight when compared with similar figures obtained from a steam locomotive performance sheet on this road for the year 1909. Maintenance per locomotive mile in cents (not including depreciation) for steam locomotive operation, year 1909, equals 16.1. Wages and materials have increased to a considerable extent since 1909 so that the comparison is not represented by the above figures.

Each locomotive averages, according to our performance sheet, 25,000 miles per year. It is readily apparent that the engine miles are unusually low. However, this is accounted for by the fact that the Interestate Commerce Commission allows six miles per hour for 90 per cent of the work performed on this road. The main line haul offers another serious handicap to engine miles. These conditions are fixed and are mentioned to emphasize the operating conditions.

It occurs to the writer that the present method of showing locomotive equipment expense per mile is, at the best, only an approximation so far as comparison is concerned with other lines. For instance, a locomotive operating in either freight or passenger service on an electrified portion of a transcontinental line can cover more miles in a given number of hours than a switch engine is allowed in twice the same number of hours. Then, too, it is generally understood that it costs more per engine mile equipment expense to maintain switchers than road engines. This explanation is offered for your consideration in connection with general costs per mile equipment expense.

Tire wear is most noticeable at the flange, making it necessary to turn the tires every year. While it is quite evident that tire turnings are more frequent than are generally reported, it does not surprise those who have the privilege of inspecting our lines. Our principal haul is infested with curves of 8, 10 and 20 deg. In all, we have 13,342 deg. of curvature existing between the mines at Butte and the Washoe Smelter at Anaconda.

The average time for each locomotive in the shop per year is ten days, while the shortest is four days. During this time a general overhauling is given to the mechanical and electrical equipment. The time for electrical inspection and repairs varies with the class of service which the locomotive has been worked at most. In general, the electrical work is completed in less than two days, bad rheostat connections and tight contactor pins giving the only cause for electrical work in the cab. Regarding rheostats — we can say that under the heaviest short work our rheostats have stood the test beyond any expectation. The first year or two of electrical operation developed a weakness which was soon overcome by replacing the jumpers between the rheostat boxes. It was our opinion at that time that we would drive the trouble from these connections into the grids, thus causing a more serious condition. Fortunately, this did not materialize. To give an idea of the unusual test made upon our rheostats it will suffice to give one example which, no doubt, is the heaviest service to which any of our locomotives have been subjected: The Concentrator spotter weighs and spots all incoming ore and receives 25 cars from the Hill hog per trip. After the Hill hog cuts off, the spotter must pull 25 cars over the scale in order to allow them to run back over the automatic scale due to gravity. This is on a 1 per cent grade. Thus it is necessary to work on sand under the most favorable conditions. The current necessary to perform this operation is approximately 350 amperes. The full load rating of the motors being 190 amperes makes it quite evident that the motors and rheostats are considerably overloaded.

Our electric locomotives are inspected approximately every forty days. Engines working at Butte or on Butte Hill have no care except oiling and renewal of brake shoes. The maximum number of days which a locomotive has been away from the shop is 70, working two ten-hour shifts per day. A close inspection gave no evidence which would lead us to believe that, under ordinary conditions, our locomotives could be inspected less frequently, if we so desired. Monthly inspections, as we call our 40-day periods, are made over a cinder pit, summer and winter. Two electrical men inspect a double unit in 20 minutes to an hour, making all necessary repairs and adjustments. One machinist inspects the mechanical parts in 20 minutes to an hour.

Seven machinists, two machinists' apprentices, four helpers, two drill-press men, one wiper, one oiler, one boilermaker and his helper, three blacksmiths and three helpers, who work on steel cars principally, a pipe fitter and his helper and a carpenter comprise the machine shop crew.

One of the first questions all my visitors ask is "How do your commutators wear?" To date, we have not turned a single commutator on account of wear. We have turned a very few due to injuries received when inspection plates were allowed to fall in on the commutators. The wear is just appreciable at this time. The color could not be improved and there is no evidence of burning or flash overs. We are using an Electro Graphitic brush which gives very good mileage and very little breakage.

They also inquire whether we have much armature trouble. Like all electric roads, we have armature trouble. However, it amounts to so little that we keep one man as an armature winder and his time is spent principally on other equipment than armatures. Recently we went one year and eleven months without an armature failure.

Steam engineers are used on the electric locomotives, and it has been our experience that this is the best practice. In the beginning an experienced man made several trips with each engineer when he took charge of an electric locomotive. The principal trouble they had was with the controller. The habit of pulling the throttle out to most any position is one that is hard to break. Lectures were held to instruct all concerned relative to the "don'ts" and to give a practical working knowledge of the equipment in general.

In the beginning, we purchased 17 electric locomotives and they did the work of 28 steam engines. A substantial reduction in the amount of overtime worked was readily apparent. With few exceptions, our electric engines are operated in pairs. This alone reduces the number of crews approximately 50 per cent.

In conclusion, it will be sufficient to repeat a question which is invariably asked by visiting railway officials — and the answer given: "How do your engines perform in heavy snow?" Having had experience with steam and electric locomotives in snow, the performance of the electric engine can only be appreciated by those who have seen it. For our service, the electric locomotive is in every respect far superior to the steam engine.

EXHIBIT G.

HISTORICAL SKETCH—NORFOLK & WESTERN ELECTRIFIED LINES.

By Mr. John A. Pilcher, Mechanical Engineer.

The Norfolk & Western Electrification is on a portion of the Pocahontas Division, familiary known as the Elkhorn grade.

Along this division are numerous colliery sidings and short branches penetrating the developed coal fields, so that the normal service consists in collecting loaded cars or trains from the sidings and branches for eastbound trips and delivering empties on the return Thus many conditions are favorable for electric traction, namely: An entire short operating division on which electric power may be substitued for steam between engine terminals without shortening or interfering with adjoining operating divisions, heavy grades where power requirements are great, and a large volume of traffic which taxes the capacity of the line because of physical limitations and slow operating speeds. In this case the primary objects of electrification were the increased capacity of the line, and economy and increased efficiency of the service generally.

The present electrification extends from Vivian to Blufield.

The first serious proposal for electrification on the Norfolk & Western was taken up in October 1904. At that time the operation of the tonnage coal trains up the hill was with four steam locomotives, and the gross weight of the train was regulated according to the rating of the engines used. The rating for the engines on this division was as follows:

Class B	600 tons
Class W	580 tons
Class T	450 tons
Class G	390 tons
Class F or I	350 tons each

The trains were operated in such a way that three of these engines could carry the loads through Elkhorn tunnel. This is on account of the extremely bad air conditions in the tunnel with four engines operating.

After passing the tunnel, an additional engine was cut off, leaving two engines to pull the train eastward to Flat Top Yard or Bluefield. The two engines cut off, therefore, were pushers. The trains were never made up with as many as four Class "W" or "B" engines in one train. They were either three Class "W" and one smaller engine or three Class "B" and one smaller engine, or a combination of three Class "B" and "W" engines and a smaller engine. By making the fourth engine a light one, the three engines were able to take the load through the tunnel that the four engines could bring up to the west portal of the tunnel. The speed of operation was very slow, dropping back to six and seven miles per hour in many cases. The average load was about 1700 tons per train.

This first idea of electrification was for the pusher service only. The electrification was to extend from Vivian up to Ruth, a distance of 14.8 miles, which is the top of the heavy grade, and just east of the Elkhorn tunnel. The estimates at that time were based entirely upon electric pusher service.

With the first study the source of power was to be gas engines using waste gas from by-product coke ovens, which were to succeed the bee hive coke ovens, which were very numerous in the vicinity. The use of gase engines was abandoned when it was found that the coal in this immediate vicinity, which is the Pocohontas coal section, did not have sufficient volatile matter to make the by-products ovens profitable, although the coal farther west from the Thacker seam, and farther to the south from the Toms Creek region could have been used in this manner.

A further study was based upon the use of a steam plant in the immediate neighborhood. During the next twelve months the whole matter was carefully studied, and the information gathered together was put into final reports made by both the Westinghouse Electric & Manufacturing Company and the General Electric Company. At the time these reports were made the tonnage passing up the grade eastbound, averaged 22,700 tons per day.

Since the electric locomotives were to be used in pusher service only, the speed had to be made such as would allow for economical operation of the steam locomotives in connection with the electric pushers. The advantages considered were as follows:

1. Increased capacity of tracks.
2. Increased reliability of service.
3. Increased flexibility of motive power.
4. Reduced cost of maintenance.
5. Additional power supply.
6. Reduction of smoke in tunnel.
7. Small cost of making extensions.
8. Furnishing source from which power can be sold.

Careful estimates were made of the cost of operation with electric pushers as compared with steam pushers, not only for the daily run of 22,700 tons, but upon different percentages of increase up to 100 per cent. At that time it was considered that the saving would amount to 9.72 per cent of the investment. With an increase of traffic of 25 per cent. it would amount to 17.07 per cent of the investment, with an increase of 50 per cent it would amount to 18.45 per cent of the investment, and with 100 per cent increase of traffic it would amount to 21.43 per cent of the investment.

The system of operation proposed by the Westinghouse Electric & Manufacturing Company was the single phase system, with multiple unit locomotives.

It was proposed to install alternating current generated at 6600 volts in a central power house, by means of single phase generators driven by steam turbines. This 6600 volt current was to be fed by suitable feeders direct to an overhead trolley wire located above the center of the track and supported by catenary cables. From this wire the current was to be carried into the locomotive through a suitable bow trolley with an auto-transformer and from there to be fed to the motors in accordance with the accelerative speed at which it was desired to operate the locomotive. The normal running voltage being 240 volts.

The locomotives proposed were to be operated under a multiple unit system, in which each unit was complete in itself, but might be coupled in parallel with any number of additional units. At that time it was considered that the Elkhorn pusher service would use a three unit electric locomotive as a pusher. If desirable to operate trains of lighter weight, a single or double unit locomotive could be employed, or if it is desirable to operate heavier trains a larger number of units might be employed in the locomotive. Each unit of each multiple locomotive being complete and independent in itself, carried a complete equipment of control apparatus, and therefore, each multiple unit locomotive could be operated by one operator from either end of any unit. Each locomotive unit was to have three pairs of 60 in. drivers and single phase motors geared to each axle by single reduction cast-steel gears. Each motor was to have a normal rating of 250 h-p., which could successfully withstand considerable overload. The locomotive was to be designed to work at its maximum drawbar pull at a speed of from 0 to 12 miles per hour, and run at a maximum speed of 25 to 30 miles per hour.

Each unit was to weigh 62½ tons, all on the drivers, giving a weight of 125 tons for a double unit; 187½ tons for a triple unit, or. 250 tons for a quadruple unit locomotive. A triple unit locomotive would be capable in itself of taking a 1500 ton train up the Elkhorn grade. This triple unit with two Class "B" steam engines in front was to make a train load of about 2700 tons.

The report submitted by the General Electric Company, based upon the same date, covered three propositions:

1. The use of locomotives fitted with direct current motors of standard design wound for 600 volts, and collecting current at the latter potential from a third rail located at the side of the track.

This system being in use at that time in connection with the installation of the Baltimore & Ohio Railroad at Baltimore, New York Central & Hudson River Railroad at New York, as well as others.

2. The use of locomotives equipped with direct current motors, as in the first case, but carrying either in the locomotive cab or on a tender, a motor generator set which receives single phase alternating current at one end and delivers from the other direct current at 550 volts suitable for operation of the motors, thus making it possible to deliver power to the locomotive by means of single phase alternating current at a potential of 3000, or if necessary, 5000 volts.

3. The use of locomotives operated by single phase alternating current motors, supplied by current from static transformers to which single phase current is delivered through overhead trolley at potential, say of 3000 volts.

The specification was drawn up for a 120-ton alternating current electric locomotive of 1200 h-p.; the locomotive to have four axles, each carrying 300 h-p., 625 volt direct current motor. In the cab of the locomotive there was to be carried a motor generator set consisting of 750 h-p., 3000 volt, 25 cycle, induction motor, and driving a 400 KW, 650 volt direct current generator.

The control was to be along the standard lines of the Sprague-General Electric multiple unit control, two or more locomotives being connected together and operated by one master controller.

Each locomotive was to have a tractive effort of 40,000 lb., with 375 amperes per motor, and to operate at ten miles per hour. The maximum speed on a level with a train of approximately 750 tons was to be approximately sixteen miles per hour. Each locomotive was to be capable of handling a 750-ton train over the running distance, about 14.8 miles, in about one and one-half hours.

The other detail specifications for the locomotive are as follows:

WHEEL BASE.

Total..........28′ 10″ Rigid..............16′

WEIGHTS.

Total weight (approx.)	240 000 lb.
Weight on drivers (approx.)	168 000 lb.
Weight on pony trucks (approx.)	72 000 lb.
Electrical equipment (approx.)	120 195 lb.

The allowable maximum weight on driving axles at this time was 42,000 lb. This is exceeded in the General Electric Company's specification, but as no definite action leading to the construction in connection with these reports was ever taken, this item was not corrected.

The question of electrification was again taken up in the summer of 1909. At this time the study was made for the complete electrification from Vivian to Bluefield.

At this time the idea was to purchase the power from some local water-power company. No definite recommendation was made on the basis of this investigation.

The matter was again taken up very earnestly in 1911, during which time a number of test runs were made of steam trains in order to get the necessary information to base proposals for electric locomotive requirements.

During 1912 comparative statements were prepared which were turned over to Gibbs & Hill, Consulting Engineers, and upon this information, as gathered, the electric equipment as finally installed was worked up.

The construction was actually started in 1913 and the locomotive operation was actually started by Gibbs & Hill in April, 1915, and by the Norfolk & Western Railway in July, 1915.

The conditions of steam operation had very materially changed since the first observations were made. The Norfolk & Western Railway Company had purchased quite a number of Mallet locomotives, each of which could take about 1080 tons up the ruling grade on this division, instead of from 580 to 600 tons.

The allowable weight per axle had increased from 42,000 lb. to 55,000 lb. At the present day the allowable load per axle on electric locomotives is 68,000 to 70,000 lb.

The eastbound load had gone up to about 50,000 gross tons per day. The capacity of the electric equipment, as installed, could handle an average of about 65,000 tons per day, in addition to handling the through freight trains by electric pushers and the passenger trains with their steam locomotives by attaching electric engines. In the latter case the necessity for an electric helper occurs only where the train is so heavy as to require doubleheading on the grade.

In connection with the steam operating conditions — it was customary under steam operation to make up the train to a maximum weight of 3250 tons behind the engine and to handle it by a Mallet road engine and a Mallet helper over the division, and, in addition, a Mallet pusher up the 1.5 per cent and 2 per cent grades, or three engines per train. In cold weather and under adverse conditions the trains were reduced to about 2900 tons. The engines were of the latest compound type fitted with mechanical stokers and superheaters. They weighed about 370,000 lb. on drivers and 540,000 lb. total, including tender, and had a tractive power of about 85,000 lb. Tonnage trains were handled normally at speeds of seven miles per hour or eight miles per hour on the grades, but on account of the ventilating conditions the speed was reduced to six miles per hour in the Elkhorn tunnel. This tunnel is equipped with the Churchill method of forced ventilation, which consists of blowing air through annular nozzles in the direction of the up-grade movement and at a slightly greater velocity than the speed of the train, thus blowing the smoke from the head of the train without having the smoke from the rear engine reach the front engine during the tunnel movement.

Because of the slow speed in this tunnel, and also because of the fact that it is of single track, a serious restriction in the capacity of the line occurs at this point and has occasioned frequent congestion and delay. Generally, however, the division is double track throughout, with frequent long passing sidings, making it in part a three-track line. Sixty per cent of the entire division is on curves, the maximum curvature being 12 deg. on the main line and 16 deg. on sidings.

From the profile it will be noted that, beginning at Vivian, there is a stretch of about 5.5 miles of 1 per cent grade to North Fork, thence 5.5 miles of 1.5 per cent grade to Ennis and then about 4 miles of 2 per cent grade to the Elkhorn tunnel, which is 3100 ft. long and on a 1.5 per cent grade. Leaving the east portal of the tunnel the line pitches down on a 2.5 per cent grade for about 1 mile and then rises again for 9.5 miles on a 0.4 per cent grade, finally reaching Bluefield over 3 miles of 1.25 per cent grade. The main gathering points for the coal occur along the line from Vivian to Flat Top Yard, and eastbound trains must, therefore, be hauled over very heavy grades.

The decision to electrify was arrived at about seven years ago and followed a careful study by the officials of the road of the actual steam operating costs on this particular division. This was done by keeping a complete detailed record of the operating costs, as well as a tabulation of the failures and delays of each steam locomotive. In this way it was not necessary to take average costs, which included operation on other divisions and under other conditions, in making comparisons with estimates of electric operating costs.

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

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

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

The electric installation comprises the equipment of 29.4 route miles of main track, or 94.82 track miles total, with an overhead trolley wire operating at a working voltage of 11,000. A power house has been erected at Bluestone, a central point on the line. It contains three single-phase turbo-generators, each of 10,000 K.W. rating for the load conditions, and the usual electrical and mechanical appurtenances, all of the most approved type. Current is generated at 11,000 volts pressure and stepped up to 44,000 volts for transmission along the line to four sub-stations. These contain static transformers which lower the voltage to 11,000 for delivery into the trolley.

The overhead structures employed to support the trolley wires embody a number of novel features in respect to the use of tubular pole bridges, the poles being reinforced by rod guys on the outside of curves. This type of structure is simple, light, and relatively inexpensive and presents a minimum obstruction to view along the tracks. Of course, all structures, wiring and attachments have been carefully calculated for the maximum stresses which may occur from temperature change, the accumulation of ice and snow, effects of wind, etc. The insulation of the trolley line has also been very carefully designed to obtain at all places double insulation to ground.

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

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

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

Electric operation has been in service too short a time to give data as to performance, but it may be said that the estimates of increased capacity to be obtained from this equipment have been fully met and that an unusually heavy tonnage has already been handled without congestion, and the gathering and delivery tracks kept clear. The movement of the heavy tonnage trains by electricity has been effected with ease and smoothness; the trains accelerate promptly and without shock or jerk on the heavy grades, and it has been found that the full trains can be smoothly controlled by one head engine on the 2.5 per cent down grade by electric braking alone and at a uniform speed slightly above that of the regular running speed. The acceleration of one of these heavy trains is impressive as regards the amount of power required. Preliminary tests indicate that getting a train in motion up the grade requires as much as 11,000 electrical horse-power and that running at uniform speed up the grade requires 8000 electrical h-p. to be delivered to the train. It is believed that no such amount of power has ever before been developed on a single train, either steam or electric, in regular service.

For convenient reference detailed technical data regarding the installation are given in the following:

Electrified Section.— Part of the Pocahontas Division extending from Bluefield, W. Va., to West Vivian, W. Va., a distance of 29.4 miles. Line is double track, with long middle passing tracks. Through the Elkhorn tunnel (3100 ft. long) the line is single track.

Track Mileage.

Main line		57.17
Passing tracks		4.05
Yards:		
Bluefield	8.54	
Flat Top	2.34	
North Fork	1.12	
Eckman	4.79	
Vivian	4.15	
		20.94
Mine-delivery tracks and sidings		5.45
Branch lines		7.21
Total track mileage		94.82
Elevation above sea level at Bluefield		2 550 ft.
Elevation above sea level at West Vivian		1 475 ft.
Total rise against east-bound traffic		1 075 ft.

Grades.— Against eastbound traffic, from Vivian to Ruth, grades are 1.0 per cent, 1.5 per cent and 2.0 per cent. The maximum curvature is 12 deg. and 60 per cent of the entire line is on curves.

Train Service.— Gathering and delivering coal tonnage into yards at termini of electrified division; also pushing through freight and helping passenger trains up the Elkhorn grade. The service includes:

Coal trains hauled eastward per day	20
Time-freight and passenger trains helped up grade	6
Total daily coal train tonnage — eastward	65 000 tons
Weight of train, excluding locomotives:	
Up 1.5 and 2.0 per cent grades	3 250 tons
On other grades	4 700 tons
Operating speed:	
On 1.0 to 2.0 per cent grades	14 m. p. h.
On other grades	28 m. p. h.
Average round-trip time, with electric service	6 hours
Average round-trip time, formerly with steam service	9 hrs. 40 min.
Number of electric locomotives provided	12
Number of Mallet steam engines displaced	34

Train Makeup.— Full tonnage trains are handled by two electric locomotives, one at head end and one pushing; manifest freight trains use one electric pusher in addition to steam engine. Heavy passenger trains, with steam road engine, have one electric helper.

Electric System.— Single-phase alternating current is generated in the power station, transmitted at 44,000 volts to sub-stations where it is transformed to 11,000 volts and fed into the trolley lines over the tracks. Current is converted into low tension three-phase on the locomotives and utilized in the three-phase proplusion motors.

Power House.— Building.— Located at Bluestone, W. Va., on Bluestone River. Building is 158 ft. by 135 ft. with 52 ft. by 33 ft. extension. Steel frame and brick construction with reinforced concrete floors and roof.

Stack.— Radial brick, 268 ft. high. Height above furnaces, 250 ft. Inside diameter, 20 ft.

Boilers.— Ten water-tube type, each of 6772 sq. ft. heating surface (677 h-p. normal, 2000 h-p. maximum rating), equipped with underfeed stokers and forced draft. Space for four additional boilers.

Generating Units.—Three 10,000 kw. turbo-generators. Total installed capacity, 30,000 kw. Overload capacity, 25 per cent. Space provided in building for one additional unit.

Condensing Plant.— Each main turbine is equipped with a jet condenser having turbine driven air and circulating pumps. Normally, condensing water is taken from the Bluestone River, but to augment the supply in times of low water a spray cooling pond, 296 ft. by 90 ft. by 5 ft. deep, is provided adjacent to the power house.

Switching Equipment.— For controlling the power supplied in and from the station. Consists of master-control switchboards with indicating instruments centralizing the control of all machines, feeders and protective devices. Also devices for automatically regulating regenerated power returned to the line from locomotives operating on down grades.

Accessories.— Include turbine-driven boiler feed pumps, feed water heaters, oil filtering equipment, coal and ash handling plants, coal storage bins, crane, storehouse, and also a central telephone switchboard communicating between power director and all parts of the plant and at intervals along the electric zone.

Sub-Stations.— Location and Capacity.— For stepping down the voltage from 44,000 to 11,000 and for switching and controlling the supply of current to the sections of the trolley line. Five sub-stations are provided as follows:

		Units	Total Capacity	K. V. A.
	No.	K. V. A.	Installed	Ultimate
Bluefield	2	3 000	6 000	15 000
Bluestone (in power house)	2	2 000	4 000	15 000
Maybeury	2	5 000	10 000	15 000
North Fork	2	3 000	6 000	15 000
Vivian (outdoor)	1	2 000	2 000	5 000
Total	......	....	28 000	65 000

Transformers.— Single-phase, oil-insulated, water-cooled type. Housed in brick buildings, except at Vivian where the sub-station is of the outdoor type.

Attendance. — Not required as there is no moving machinery and the switches are operated electrically by regular railroad attendants at passenger stations, yardmasters' offices, etc.

Transmission Lines.— Consist of two single-phase circuits, using four 2-0, seven-strand, hard drawn copper wires, mounted on pin type insulators and carried on the catenary structure, except over the tunnels where the lines are carried on wooden poles.

Catenary Trolley Line.— Consists of 3-0 special bronze trolley contact wire and 1-0 copper auxiliary messenger wire supported by ½-in. galvanized steel messenger wire and triple insulators which are supported by steel bridges spaced up to 300 ft. apart. The catenary bridge structures consist of H-beams supported by tubular poles guyed on outside of curves. For anchor and signal bridges built-up poles are used. On colliery sidings and branches wood pole supports, spaced 100 to 150 ft. apart, are used. Normal height of trolley wire, 24 ft. above rail. Height of trolley wire in Elkhorn Tunnel, 16 ft. 9 in.

Return Circuit.— Track rails are double copper bonded for the return circuit, impedance bonds being used at signals. Track transformers are used to prevent inductive disturbances in telephone and telegraph lines and are connected at intervals of about one mile.

Locomotives.— Locomotives are of the articulated type. each consisting of two units, each having two main trucks connected by Mallet hinges, each truck being provided with two driving and one guiding axle. Motors are mounted on main truck frames and geared to the jack shafts, which are connected to driving wheels by side rods. Cabs contain electric apparatus for transforming, converting, switching and controlling the electric power, and for the air brakes. Locomotives operate normally at speeds of 14 m. p. h. or 28 m. p. h., as desired. On down grades power is automatically returned to the line when holding the train at normal speeds without application of brakes.

Number of locomotives	Twelve
Type	Articulated geared side rod
Classification	2-4-4-2 2-4-4-2
Driving wheels	Sixteen, 62 in. diameter
Truck wheels	Eight, 30 in. diameter
Weight on drivers	440 000 lb.
Total weight of locomotive	540 000 lb.
Length, overall	105 ft. 8 in.
Width, overall	11 ft. 6¼ in.
Height above rails	16 ft.
Rigid wheel base	11 ft.
Total wheel base	83 ft. 10 in.
Number of motors	Eight
Type of motors	Three-phase induction
Air compressors (two), capacity, each	75 cu. ft. per min.
Main reservoirs (eight), total capacity	180 000 cu. in.

Rating at	14 M. P. H.	28 M. P. H.
Maximum accelerating rating of locomotive	4 500 h.p.	6 400 h.p.
One hour rating of locomotive	3 300 h.p.	3 300 h.p.
Continuous rating of locomotive	2 600 h.p.	3 000 h.p.
Maximum accelerating tractive effort of locomotive	125 000 lb.	90 000 lb.
One hour tractive effort of locomotive	87 000 lb.	44 000 lb.
Continuous tractive effort of locomotive	68 000 lb.	40 000 lb.

Inspection building located adjacent to power house. Steel frame and brick construction, with reinforced concrete floor and roof. Dimensions, 148 ft. by 68 ft. Contains two pit-tracks, wheel pit, 30-ton power operated crane, and full complement of machine tools for locomotive maintenance.

If further information in regard to this equipment and the electrification is desired, it can be found in the following pamphlets:

New York Railway Club — meeting of March 19, 1915, paper by Geo. Gibbs.

Electric Railway Journal, June 5, 1915 — Description of Norfolk & Western Electrification.

New York Railway Club — meeting of March 16, 1917, paper by C. H. Quinn, Chief Electrical Engineer, Norfolk & Western Railway.

EXHIBIT H.

CHICAGO, MILWAUKEE & ST. PAUL RAILWAY — SYNOPSIS OF ELECTRIFICATION

By H. R. Warnock, General Superintendent Motive Power.

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

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

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

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

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

For the purpose of developing a market for power, as well as to develop electrified operation and to secure the savings therefrom, the Butte, Anaconda & Pacific was electrified at 2400 volts, D. C., the contract being made with the General Electric Company, the engineering being done by the Montana Power Company and the General Electric Company. The installation comprised seventeen 80-ton locomotives with a maximum draft on the power system at any one time somewhat less than 8000 kw. The result of this undertaking was successful financially as well as technically.

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

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

The railroad entered into a similar contract for the extension of the electrification to include the Missoula Division from Deer Lodge, Mont. to Avery, Ida., this involving as well the transfer of the Thompson's Falls Power site to the Montana Power Company's interests. About this time it was found that the original basis for the company's load diagram was fictitious, that the traffic was not balanced east and westbound, but fluctuated widely, due to seasonal and local variations. It was also concluded that 1600-ton trains in trans-continental service were entirely too small for the efficient movement of traffic. This led to the determination that the minimum trains should be 2500 tons hauled by a single locomotive on a 1 per cent grade. A third conclusion was that the topography of the road was particularly suited to regeneration and that this would be required. A fourth conclusion, which was insisted upon, was that automatic means should be provided for the limitation of the maximum demand for power.

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

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

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

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

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

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

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

Construction.

Topography.— Work was commenced on the Rocky Mountain Division in 1914 and completed on the Missoula Division in 1917, giving a continuous main line electrification of 438 miles from Harlowton, Mont. westward to Avery, Ida. Near the center of this section is Deer Lodge and the east end is called the Rocky Mountain Division, while the west end is called the Missoula Division.

At Deer Lodge are located the repair shops and this is also the headquarters of the Operating Department which consists of a superintendent for the whole district, having two assistants, one for each division.

In proceeding westward from Harlowton, the first mountain range encountered is the Big Belt Mountains, on which our road reaches an elevation of 5788 ft. above sea level. The next range is the Rocky Mountains, which are crossed at an elevation of 6322 ft. On the Missoula Division are encountered the Bitter Root Mountains, the maximum elevation reached being 4163 ft. For 21 miles on the eastern slope of the Rocky Mountains is encountered the maximum grade of 2 per cent. The maximum curvature in the electrified zone is 10 deg.

The temperature range is from 100° to minus 45° F. The snow fall is comparatively light, excepting in the Bitter Root Mountains where it is very heavy, requiring almost the continuous use of snow plows for the several winter months.

Power Supply.—Power is furnished to the Chicago, Milwaukee & St. Paul power tap at sub-stations by the Montana Power Company over their three-phase, 60-cycle, 100,000-volt, transmission line, from their plants located as follows:

Volta on the Missouri River near Great Falls........60 000 K. W. capacity
Rainbow Falls on the Missouri River near Great Falls..27 000 K. W. capacity
Holter on the Missouri River near Helena...........40 000 K. W. capacity
Madison on the Madison River....................12 000 K. W. capacity
Thompson's Falls on Clark's Fork of the Columbia River..................................30 000 K. W. capacity

Transmission.—The transmission line consists of 2/0 B & S, 6-wire hemp core copper cable and one ⅜ in. S. M. stranded ground wire supported on wooden poles. Insulators of the suspension disk type are used, six in suspension, and seven in strain position. Cedar poles are used, standard length on level being fifty feet. Lengths elsewhere as governed by profile.

The normal pole spacing on tangent level is 300 ft.

Sub-Stations.—The sub-stations are fourteen in number, indoor type spaced on an average of 32.7 miles apart. Current is received over either the Montana Power Company or the Railroad Company's 100,000-volt transmission line, then transformed to 2300 volts and delivered to the motors of the motor generator sets.

Each motor generator set consists of a synchronous motor, direct connected to two 1500-volt direct current generators, permanently connected in series to give the 3000-volt trolley current. The motor generator will carry a normal rated load continuously, 50 per cent overload for two hours or a 300 per cent overload for five minutes.

During regeneration by a locomotive, the direct current generators become motors and drive the synchronous motors as a generator. A high-speed circuit breaker is connected in the negative lead running to the track. The function of this breaker in conjunction with flash guards mounted between the brushes and adjacent to the commutators and generator is in case of a short circuit of the trolley lines to introduce a resistance in the D. C. circuit before the circuit rises to a value sufficient to cause flash-over of the generators. The current thus being reduced to a value readily handled by the regular switch board breakers. The following table shows the location and capacity of the sub-stations in their order westward.

Sub-station	M-G Sets		Total Capacity of Sub-stations
	Number	Capacity	
Two Dot	2	2 000 kw	4 000 kw
Summitt	2	2 000 kw	4 000 kw
Josephine	2	2 000 kw	4 000 kw
Eustis	2	2 000 kw	4 000 kw
Piedmont	3	1 500 kw	4 500 kw
Janney	3	1 500 kw	4 500 kw
Morel	2	2 000 kw	4 000 kw
Gold Creek	2	2 000 kw	4 000 kw
Ravenna	2	2 000 kw	4 000 kw
Primrose	2	2 000 kw	4 000 kw
Tarkio	2	2 000 kw	4 000 kw
Drexel	2	2 000 kw	4 000 kw
East Portal	3	2 000 kw	6 000 kw
Avery	3	1 500 kw	4 500 kw
Total Capacity			59 500 kw

Overhead Trolley Construction.— The trolley is of catenary type, supported by brackets on wood poles with poles on outside of curves for single track excepting in cases of curves of short lengths where, to avoid feeder crossing, span construction is used. Span construction is also used for two or more tracks. In tunnels the catenary or feeder wires are attached by Crosby clips to a 4-in. horizontal steel channel suspended by two 10-in. disk insulators connected in the case of a line tunnel directly to eye bolts in the roof, and in unlined tunnels, where eye bolts are at different levels, by means of a stranded wire.

Trolley catenary or messenger is of ½ in. galvanized high strength steel seven-strand wire. The messenger wire supports two 4/0 B & S grooved trolley wires which hang side by side, there being a hanger alternately attached to either trolley wire, every 7½ ft.

The trolley wire is maintained at a height of 24 ft., 2 in. above the track. The feeder is continuous from one sub-station to another, and is taped to the trolley wire at intervals of 1000 ft. The feeder for 85 per cent of the line is 500,000 c. m. cable. The other 15 per cent represents heavy mountain grades and consists of two 500,000 or 700,000 c. m. cables. At the beginning and end of every passing track the trolley and feeder are sectionized by section switches mounted on poles.

Bonding.— Return circuit consists of 85 lb. or 9 lb. running rails and an auxiliary 4/0 B & S copper strand mounted on poles. Both rails of main line are bonded and one rail of side tracks. One 250,000 c. m. bond per joint is used, except on mountain grades (over 1 per cent), where two such bonds per joint are used. Bonds are of pin type, exposed or concealed, depending upon character of the rail joint. The auxiliary 4/0 wire is intended to act as a temporary shunt circuit to the rails in case, through accident, the circuit through the rails should be interrupted.

Signals.— The signals are operated by a 4400-volt, 60-cycle, circuit, consisting of two No. 4 B & S wires fed from the sub-station, the system used being union A. C. color light automatic block.

Power Indicating and Limiting Circuit.— System consists of a circuit of two No. 8 copper wires, running from the first to the last sub-station, and supplied with constant voltage from a smaller motor generator, located in the Dispatcher's office, the voltage on the circuit depending upon the particular value of the demand to which it is desired to limit the system load. In each sub-station where there is a Power Company feed tap, there is installed a so-called "contact-making." wattmeter, which introduces into the P. I. & L. circuit, an additional ohmic resistance whose amount varies with the load supplied at such feed tap. There is also in each sub-station automatic apparatus, which, when the total kilowatts used in the system reaches the amount optioned for, and consequently when the current in the P. I. & L. circuit reaches a certain value, causes resistance to be inserted in the fields of the sub-station generators of the motor generator sets, and this reduces the voltage on the trolley system, causing the speed of all trains to be decreased. The maximum reduction in load thus obtainable is about 30 per cent of that which would be used in case the P. I. & L. system were not provided. In the Dispatcher's office there is a switchboard on which is mounted apparatus for controlling the small motor-generator set supplying the system, and also an indicating and a curve-drawing wattmeter which show for any instant the total kilowatts supplied by the Power Company.

Locomotives.— Forty-two main line electric locomotives, including thirty freight and twelve passenger locomotives, and, in addition, two switching locomotives, were provided for this electrified zone, and were manufactured by the General Electric Company, principally at their factory in Schenectady, N. Y. The railway company felt conditions similar to those existing on its line, as far as passenger service was concerned, had not before been met and that it would be desirable to finally determine upon a proper design of passenger locomotive only after a suitable period of actual electrical operation had been experienced. For passenger service, it was therefore determined to use the standard freight locomotive, with no other changes than to provide a gear ratio suitable for passenger speed and to equip the locomotives with train heating and lighting equipment. General data applying to freight locomotives will be found in the following table:

Type of locomotive	3 000 volt d. c.
Length over-all	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	38 in.
Number of driving motors	8
Voltage per motor (full parallel)	1 500 volts
Total out-put (continuous rating)	3 000 h.-p.
Total out-put (1 hr. rating)	3 440 h.-p.
Tractive effort (continuous rating)	71 000 lb.
Per cent of weight on drivers (tractive co-efficient)	15.83
Speed at this tractive effort at 3 000 volt	15.75 m. p. h.
Tractive effort (1 hr. rating)	85 000 lb.
Per cent of weight on drivers (tractive co-efficient)	19
Speed at this tractive effort at 3 000 volt	15.25 m. p. h

Main line locomotives are constructed in two units, left permanently connected together, the halves, however, being duplicates and each capable of independent operation if necessary. The locomotives may be operated from either end. The four driving trucks on each complete locomotive are connected together by articulated joints The side frames of the end trucks are extended to provide for swivel connection of four-wheel leading trucks of the Woodard type.

Each driving motor is twin-geared to its driving axle, a pinion being mounted on each end of the armature shaft, and connected to its driver through a spring gear which compensates for any difference in alignment of the pinions, reduces wear and diminishes the effect of shocks to a minimum, as well as rendering operation comparatively noiseless. The motors have spring nose suspension. They are of commutating pole type, and constructed with longitudinal ventilating ducts in the armature for forced ventilation from a blower in the cab.

The control equipment is the Sprague G. E., type M, arranged for multiple operation. The 3000-volt contactors, or switches energized through the enginemen's controller, are mounted in steel compartments inside of the locomotive cab, with convenient aisles for inspection and repairs. Current for the control circuits is supplied from a motor-generator set, which in addition provides current for cab and train lights, and for exciting the motor fields during periods of regeneration. The blower for ventilating the traction motors is also direct-connected to one end of this set.

The pantograph collectors, one of which is mounted on each half of the locomotive, are of the sliding type with a working range of 17 to 26 ft. above top of rail. The pantograph is equipped with two pans, so connected together, that if one pan tends to leave the wire, due to any irregularity in the latter, this action causes the other pan to be forced up against the wire. The contact elements are of copper.

The air-brake equipment is practically the same as that used on the railway company's steam locomotives, except, of course, that motor-driven compressors are used, each being of 150 cu. ft. capacity. 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 locomotive for the oil-fired steam boilers.

Heating of passenger trains is accomplished by means of a flash boiler fired with crude oil, similar to that used on the railway company's oil-fired steam locomotives.

Regeneration.— All the main line locomotives are provided with apparatus and connections for allowing of regeneration on down grades, the motors then acting as separately excited generators and furnishing current to the trolley system, this current flowing directly over the trolley wires to other locomotives which are motoring, or flowing back through the adjacent sub-stations and eventually into the high-tension transmission line to other sub-stations, or into the power company's system. The advantages of regenerative braking may, therefore, be summarized as follows:

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

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

(3) A saving of from 10 to 15 per cent in the total power consumption.

(4) Maximum safety in operation assured by a duplicate braking system, relieving the air brakes.

(5) Increased comfort to passengers and reduced wear and tear on equipment owing to uniform speed on grades.

Switching Locomotives.— General data on the switching locomotives is given below:

Length inside knuckles	41 ft. 5 in.
Height over cab	14 ft. 3 in.
Height trolley down	16 ft. 8 in.
Width over all	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 per cent	42 000 lb.

Swivel truck type.
Weight 70 tons each.
Equipped with four geared motors.
Single pantograph.
Type GE-255 motors, box frame, commutating-pole, single-geared type, designed for 1 500 volts, with an insulation of 3 000 volts to the ground.

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

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

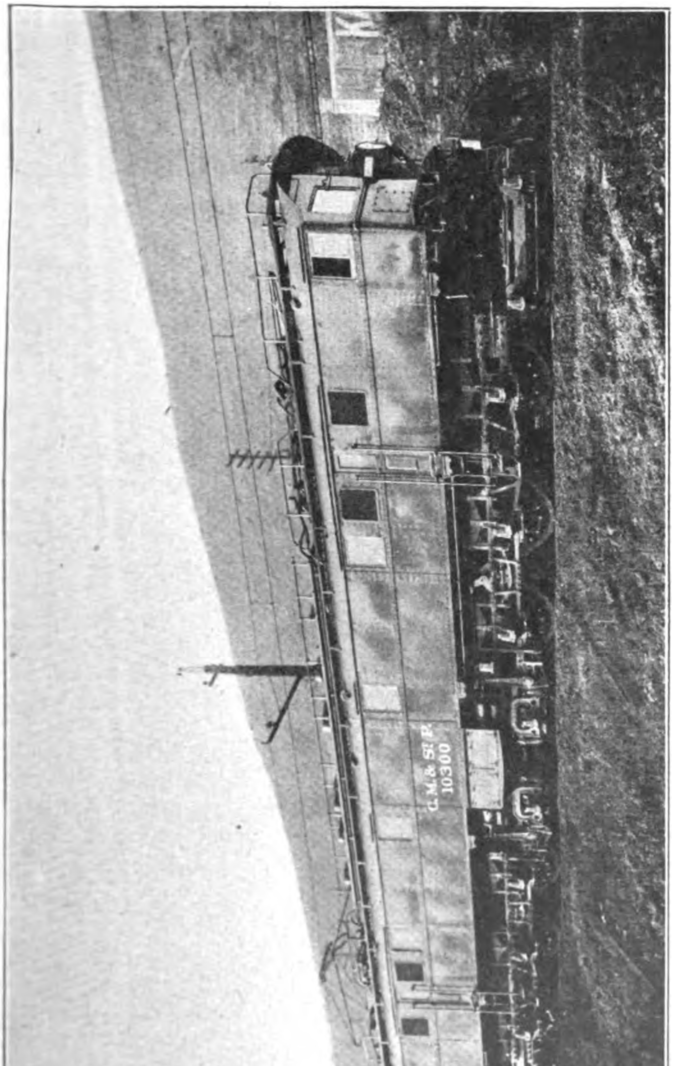
Locomotive for passenger service will be of the G. E. bi-polar type, having a total weight of approximately 265 tons and capacity sufficient to haul over the profile at a speed of approximately 25 miles per hour a twelve-car passenger train weighing 960 tons. Delivery of these locomotives will commence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

The sub-stations will be eight in number. The three most easterly sub-stations, Taunton, Doris and Kittitas, will be equipped with apparatus manufactured by the Westinghouse Electric & Manufacturing Company, and the sub-stations on the Coast Division, that is, Cle Elum, Hyak, Cedar Falls, Renton and Tacoma Junction, with apparatus manufactured by the General Electric Company. Arrangement of the sub-stations is similar to that on the Rocky Mountain and Missoula Divisions, except as to apparatus. Interesting new features are the high speed circuit breakers installed in the circuits of the individual motor-generator sets in the General Electric sub-stations and the so-called "flash-suppressors" connected to each of the individual motor-generators in the sub-stations containing Westinghouse apparatus. The function of these breakers and suppressors is to limit the current flowing from the direct-current generators, in case of short circuit, to an amount which can easily be handled by the regular switchboard breaker and which is not sufficient to cause flash-over. Another feature of interest is the addition of horn-gap feeder switches outside the sub-station, installed in the direct-current feeder circuit so as to permit of cutting off at any sub-station the flow of current from adjacent sub-stations in case of short circuit or trouble at the switchboard of the station in question. These switches are capable of opening a circuit carrying current of over 7000 amperes at 3000 volts.

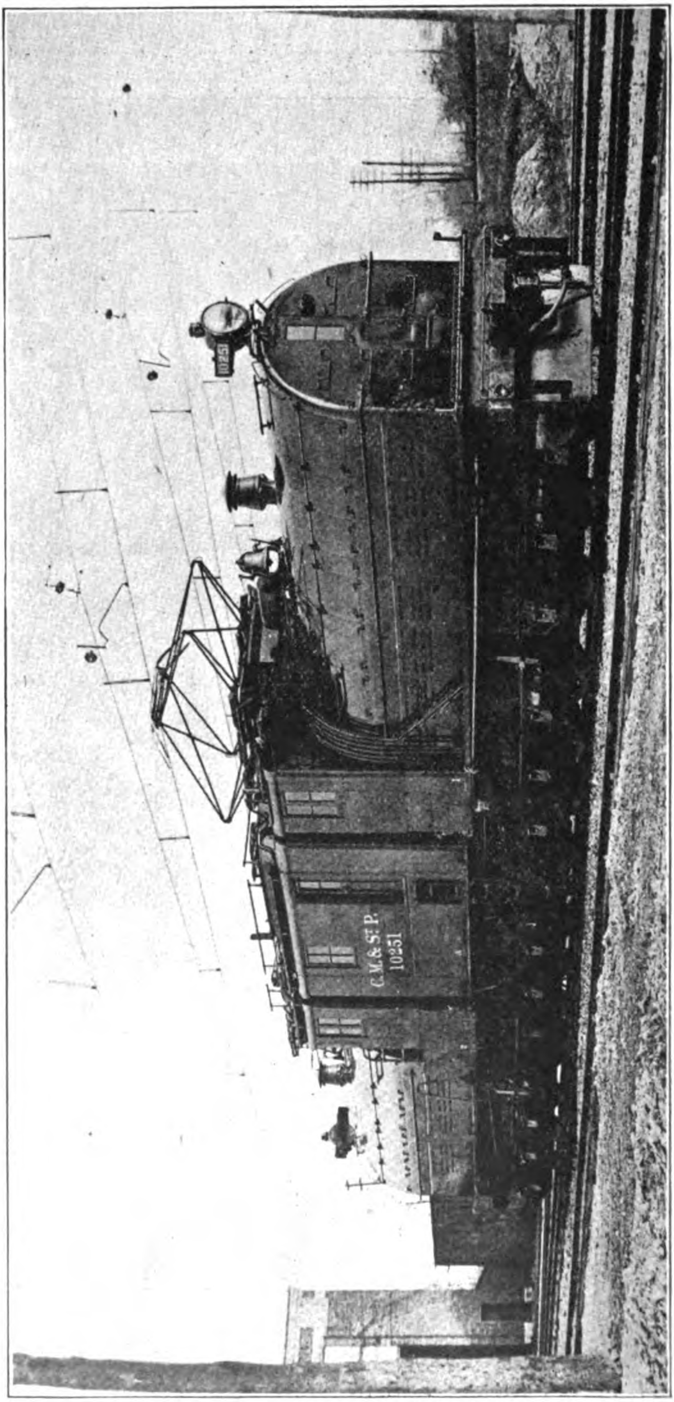
Power will be supplied over two transmission lines, one running from the Long Lake plant of the Washington Water Power Company to the Taunton sub-station, and the other from the Snoqualmie plant of the Puget Sound Traction, Light & Power Company to Cedar Falls and Renton sub-stations, these lines connecting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

Operating Organization.—The two divisions, that is, the Rocky Mountain and Missoula divisions, are under one superintendent, who has two assistants, one for the Rocky Mountain and one for the Missoula Division. Train dispatching is done from Deer Lodge by telephone, one set of three dispatchers handling the Rocky Mountain Division and another set of three dispatchers handling the Missoula Division.

Under steam operation there were two Division Superintendents, one located at Three Forks and another at Missoula. Each of these points



275-Ton, 3000-Volt, Direct Current Baldwin-Westinghouse Locomotive.
Built for Chicago, Milwaukee & St. Paul Railway.



3000-Volt Gearless Passenger Locomotive, Chicago, Milwaukee & St. Paul Railway. Class 6886-E-530-12GE100A.

had two sets of dispatchers operating in either direction which made a total of four dispatching districts.

Electric locomotives run from Deer Lodge through to Harlowton and Avery, respectively. Under steam operation, locomotives were changed at the intermediate engine points, that is, Three Forks, approximately half way between Deer Lodge and Harlowton, and at Alberton, half way between Deer Lodge and Avery. The radius of the locomotives has, therefore, been doubled. Steam locomotive engineers, after having been properly instructed, were used as electric locomotive engineers. Locomotive repair shop is located at Deer Lodge, two men being located at Avery and Harlowton, respectively, to attend to light inspection at these two electrification terminals. The Master Mechanic at Deer Lodge has general charge of sub-stations, a supervisor of sub-stations being in direct charge of the latter. Three operators, each working an eight-hour shift, are provided at each of the sub-stations. Maintenance of the trolley and transmission lines is under the charge of a General Foreman of Maintenance, reporting to the Superintendent of the two divisions. In general, three maintenance crews are used, each consisting of a foreman, two linemen and helper provided with suitable work train.

From Mr. E. Sears, Division Master Mechanic, Chicago, Milwaukee & St. Paul Railroad.

Regarding my experience with varying D. C. voltages which have come under my observation, and as to my opinion of these voltages, will say that the only thing I noticed any great difference with 3000 volts in connection with the maintenance of equipment is that it is affected more by weather conditions, that is, all resistance units have to be kept freer from moisture.

With 600-volt equipment, as on the New York Central, and 1500-volt, as on the Southern Pacific, with which road I was connected for three years, I saw very little difference as to the characteristics of the 600 volts and 1500 volts due to moisture on the main resistance elements, for in either case you could have them coated with snow and ice and not experience any special difficulty from grounding. It is entirely different with 3000 volts, as very little moisture on the resistance will cause it to jump to ground. Also, with 3000 volts operation we have learned by experience that it is bad policy to try to break heavy currents unless we break them through resistance, for the vapor and fumes formed by the copper will cause it to jump as far as six feet. I do not know how much farther it might go, but in our particular case six feet took it to ground. This experience was brought about by our not having any circuit breakers on these engines and breaking our main motor currents through twin contactors. The result being that we got a great many burnt up contactors. It was finally decided to insulate the interior so as to suppress this condition of arcing to ground, with the result that we got grounds, as above stated, where it actually jumped six feet. This has all be done away with by the insertion of a small amount of resistance ahead of the contactors when breaking arcs. Our new locomotives are equipped with a high speed circuit breaker so that we no doubt will not have any trouble from this source.

In the matter of keeping insulators and other parts cleaned to do away with creepage of 3000 volts, I do not find that there is any more trouble with 3000-volt equipment than there is with 600-volt. The insulators for insulating this 3000-volt equipment naturally have more insulated surface than the 600-volt equipment. My personal opinion is that the 3000 volts is more preferable for operation than the 600 volts, for the reason that you are working on less current and contactors have greater life as to their tips, etc. We have never had contactors freeze together, and they require very little attention. The arc chutes require less attention as they are not being called upon to sustain the high heat caused by breaking high currents. It is possible to space your sub-stations, etc., farther apart with the higher voltage operation. Our sub-stations are approximately 30 miles apart, and we get about 600 volts drop between stations under normal operation. We do experience greater fluctuation in voltage, but this is brought about by the power-limiting apparatus which is designed to keep down the peak load. I consider our method of collecting current from the overhead as being an ideal method. We have a double 4-0 trolley wire and this gives us absolutely sparkless collection. The trolley wire on the main line shows very little wear and, judging by the wear it now shows, it should last in the neighborhood of 100 years before it would be worn out. I have a piece on my desk that has seen three years' service and it is worn very little. I will send you a sample of it in a separate package.

Our pantagraphs are greased with a graphite grease. These are greased at terminals and require no further attention on the road. The average life of pantagraph strips is from nine to ten thousand miles. Would say that they can be more cheaply maintained than a third-rail shoe, although they are very susceptible to being torn off on account of the overhead getting out of alignment. Personally, I think this is somewhat due to our method of maintenance, which probably could be improved upon, as it appears to me that the overhead maintenance crew depends upon the pantagraph to show where the bad place in the overhead is, after pantagraph is torn off, before they make repairs. The Southern Pacific maintains their 120 miles of electrification differently, and I understood from their electrical engineer that they only lost two pantagraphs this summer, while in the hot weather, when the expansion is the greatest, we lost as high as 15 one month. Usually we have more of our pantagraph trouble in July and August, due to expansion from heat. It has been found that we get about three feet of expansion to a mile on a hot day. If there is anything further that you would like to have me advise you on — as to costs, etc.— I will be glad to do so.

In the meantime, Mr. Warnock's office is taking up the matter regarding the new material. The spring gear on our passenger engines has been a great success, for after four years' service they show practically no wear at all, either on the gear or pinion teeth or the spring arrangement. On our freight engines the gear and pinion teeth show no wear, but the spring arrangement has been a source of great trouble. The reason for the difference is that the spring gear design on the passenger engines is much more sturdy, while on the freight engines, due to mechanical limitations, the design is weak and there is a limit due to mechanical conditions in making the design stronger, on account of clearances, etc. I believe that the spring gear is a great thing if it can be properly designed, which it no doubt can be on motors that may be designed in the future, but I believe the bi-polar engine is so far ahead of any geared engine that any road would be foolish to purchase a geared engine, and I trust that our G. E. bi-polar locomotives we are getting will uphold my views in this matter, as I firmly believe this type of engine is an engine that will eventually come to the front in steam road electrification on account of its simplicity, and do not believe that the old argument of dead weights is to be considered any more hazardous or undesirable as to track conditions than a geared type of engine.

EXHIBIT I.

THE LONG ISLAND RAILROAD ELECTRIFICATION.

By Mr. G. C. Bishop, Superintendent Motive Power.

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

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

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

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

The electrification covers practically this network, and within a radius of 30 miles contains 88 route miles with a total main line track mileage of