PROCEEDINGS

OF THE

TWENTY-FIRST ANNUAL CONVENTION

OF THE

American Railway Engineering Association

HELD AT THE

CONGRESS HOTEL, CHICAGO, ILLINOIS

March 16, 17 and 18, 1920

VOLUME 21

PUBLISHED BY

AMERICAN RAILWAY ENGINEERING ASSOCIATION
CHICAGO

1920

Appendix D

(ITEM No. 6) WATER POWER

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A. H. ARMSTRONG,
D. J. BRUMLEY,
R. H. FORD,
M. SCHREIBER,
F. E. WYNNE,
Sub-Committee.

(1) Water Power:

In the preparation of the report on Water Power for the generation of electricity for the operation of trains, it was considered necessary to inspect an installation of importance and magnitude in actual service. The installation selected was that of the Chicago, Milwaukee & St. Paul Railway, and that portion of its electrified division was inspected by the Committee between Harlowton and Deer Lodge. The electric power for this installation is obtained from the Montana Power Company, and several of its more important water power developments were inspected by the Committee.

(2) Source, Dams, Power Houses:

The Montana Power Company was organized in 1912 for the purpose of consolidating and unifying the business and power systems then owned by the Butte Electric & Power Company, the Missouri River Electric & Power Company, and their respective subsidiary companies. Subsequently, the Montana Power Company acquired the Great Falls Power Company and the Thompson Falls Power Company, and by virtue of the original consolidation proceedings, the Montana Power Company became vested with title to all of the property, rights and franchises of the systems owned by the Butte Electric & Power Company, the Missouri River Electric & Power Company and their subsidiary and associated companies.

The Great Falls Power Company and the Thompson Falls Power Company have been continued as separate corporate entities.

This has given to the Montana Power Company the ownership of all the undeveloped power sites on the Missouri River in the vicinity of Great Falls, which had been owned for more than twenty years by the Great Falls Power & Townsite Company, a company organized and owned by the late James J. Hill and his associates.

The Montana Power Company has developed and now owns twelve hydro-electric plants and four steam plants. It develops 290,000 horsepower and has about 1900 miles of high-tension lines, with seventy-five sub-stations.

From five of the more important hydro-electric plants, high-tension power lines, approximately 541 miles in length, radiate to and connect with seven sub-stations of the Chicago, Milwaukee & St. Paul Railway. These five plants are the following:

Madison Hydro-Electric Plant located on the Madison River with a capacity of .... 12,000 kw.

Holter Hydro-Electric Plant located on the Missouri River with a capacity of .... 40,000 kw.

Rainbow Falls Hydro-Electric Plant located on the Missouri River with a capacity of .... 35,000 kw.

Great Falls, or Volta, Hydro-Electric Plant located on the Missouri River with a capacity of .... 60,000 kw.

Thompson Falls Hydro-Electric Plant in Sanders County, near the westerly boundary of the State, located on Clark's Fork, with a capacity of .... 30,000 kw.

The water flows from the Gallatin, Madison and Jefferson Rivers, which, by their confluence at Three Forks, form the source of the Missouri River and supply water to the plants located on the Missouri River; also from Clark's Fork, a tributary of the Columbia River, water is supplied to the Thompson Falls plant.

At the head of the Madison River is the Hebgen storage reservoir, with a capacity of 325,000 acre-feet (an acre-foot equals 43,560 cu. ft.) This is the highest impounded water supply on the Missouri River, and to a certain degree insures a uniform supply of water to the turbines of the power plants below by furnishing a supply during the low-water stage of the river. It is the seventh largest storage reservoir in the world and furnishes, with the aid of the smaller storages available at each plant, a regulation of the flow of the Madison and Missouri Rivers probably unequaled by any power system in the world.

(3) Elements Entering Into the Cost of Current:

To compute the actual cost of current delivered to the railroad substations, it is necessary to obtain the first cost of the installation in order to ascertain the fixed charges. It should be understood in the cost figures given below that it would hardly be possible to get the cost so low in an isolated railroad plant. The Montana Power Company has much greater capacity than is required for the railroads and the additional power is used for other commercial purposes. Generally speaking, the first cost of the hydro-electric plants was approximately $100 per kw. This amount can be sub-divided as follows:

Water rights, reservoirs, dams and all appurtenances, outside of the power house	$65.00
Power house and equipment	35.00
Total	$100.00
The minimum kw. contracted for by the railroad, per hour, is about 30,000, which at $100 per kw. first cost would amount to	$3,000,000
Transmission lines, say, 250 miles at $4,000 per mile	1,000,000
Total investment of	$4,000,000

The fixed charges:

Interest	6.0 per cent.
Depreciation	2.5 per cent.
Taxes	1.5 per cent.
Total	10 per cent.

Annual fixed charges	$400,000.00
Annual operating expense at $8.00 per kw	240,000.00
Total cost of power	$640,000.00

The Electrification of the Chicago, Milwaukee & St. Paul Railway

(4) Transmission Lines:

This installation has demonstrated that the transmission of railway electric power over long distances is efficient, economical and reliable at 110,000 volts.

The multiple feed points at which the power company's separate lines connect to the railways lines are desirable, because:

(a) They secure for the railway the advantages of duplicate transmission lines with the actual construction of a single line.

(b) They permit the use of the railway's line for transferring power between the power company's lines.

Cedar pole construction with treated butts ("H") frames for the power company and single poles for the railway under Montana conditions is reliable and more economical than steel towers, both in first cost and annual charges.

No. 2/0 (six stranded copper wire with hemp core or equivalent diameter) is the minimum size of cable for avoiding corona losses at 110,000 volts in this climate at these altitudes.

The satisfactory lightning protection is obtained by the use of lightning arresters at the power houses and sub-stations with a ground wire along the transmission line.

The minimum spacing of the conductors is nine feet apart for 110,000 volts and has proved adequate.

Adjusting the tension in the conductors so that at 0° Fahrenheit with ½-inch sleet coating and wind pressure of 3½ lbs. per square foot, the stress will be slightly below the elastic limit, produces a satisfactory construction in this territory.

Transposition of telephone wires every one-half mile and of the railroad dispatching telephone wires every 900 feet, without transposition of paralleling power wires, gives adequate correction of interference.

It is practicable to employ short cuts for railway transmission lines by leaving the right-of-way where track curvature is great.

Sectionalization of power company's lines by switching stations located 15 miles apart provides for rapid location and correction of line failures.

The sectionalization secured on the railway company's transmission line by looping it through sub-stations (spaced approximately 32 miles) is sufficient.

Treatment of pole butts for 8 feet by boiling in creosote, which is allowed to cool before the poles are removed, has been found advantageous and gives about 15 years of life.

(5) Sub-stations: Buildings and Apparatus:

There are fourteen sub-stations on the 440 miles of road comprising the present electric zone of the C. M. & St. P. Ry. The location and equipment of each is given in the following table:

C. M. & ST. P. RY.—LOCATION AND EQUIPMENT OF SUB-STATIONS

Sub-sta. No.	NAME	Miles From Harlowton	Miles Between Substations	No. of Units	K. V. A. RATING			Size of Feeder Cir. Mils
					RATING		Total KW. Rating of Substations	
					KW. M.G. Sets	KVA. Trans.		
1	Two Dot....	12.0	....	2	2000	2500	4000	1-500,000
2	Loweth......	45.6	33.6	2	2000	2500	4000	1-500,000
3	Josephine....	75.8	30.2	2	2000	2500	4000	1-500,000
4	Eustis.......	105.8	30.0	2	2000	2500	4000	1-500,000
5	Piedmont .‡	148.5	41.5	3	1500	1900	4500	1-500,000
6	Janney......	175.9	28.6	3	1500	1900	4500	2-700,000
7	Morel.......	209.3	33.4	2	2000	2500	4000	1-500,000
8	Gold Creek..	244.9	35.6	2	2000	2500	4000	1-500,000
9	Ravenna....	277.6	32.7	2	2000	2500	4000	1-500,000
10	Primrose....	315.4	37.8	2	2000	2500	4000	1-500,000
11	Tarkio......	352.0	36.6	2	2000	2500	4000	1-500,000
12	Drexel.......	390.1	38.1	2	2000	2500	4000	1-500,000
13	East Portal..	413.9	23.8	3	2000	2500	6000	*2-500,000
14	Avery.......	437.6	23.7	3	1500	1900	4500	†2-500,000
	Total...	....	....	32	....	....	59500	

*The double 500,000 cir. mils feeder is continuous from Haugan to Avery, except where the railroad makes a loop of 2.5 miles. Here one feeder follows the track and the other cuts across the loop a distance of 1,000 feet and joins the trolley again. A 500,000 cir. mils negative feeder is also taken across this loop.

†In this section the railroad makes a loop of 8.3 miles which is 1.12 miles across. Here, in addition to the double 500,000 cir. mils feeder around the loop, there is a 500,000 cir. mils positive and a 500,000 cir. mils negative feeder taken across at the narrow point.

‡From a point 6.85 mi. west of Piedmont Substation to a point 12.19 mi. west there is a cutoff 2.13 mi. long, on which two 700,000 circular mil. cables are run, one positive and one negative, one 700,000 circular mil. positive cable following the track.

From a point 15.79 mi. from Piedmont Substation to a point 18.61 mi. from Piedmont Substation there is a cutoff 1.94 mi. long. Cables along this cutoff and around track as described for preceding cutoff.

(6) Sub-station Buildings:

The sub-station buildings are of brick and steel and are divided by a brick partition into two rooms, one containing the stepdown transformers, lightning arresters, oil switches, etc., and the other the motor-generator sets, switchboard, quick acting circuit breaker and power limiting apparatus. A small office which can be shut off from the motor generator compartment is provided for the operators.

(7) Sub-station Apparatus:

The power transformers in the sub-stations are three phase transformers, stepping the voltage of the 100,000 volts transmission down to

2300 volts for the synchronous motors forming part of the motor generator sets. There is a three phase transformer for each motor generator unit. These transformers are connected to the 110,000 volt lines or bus by means of oil switches, and to the synchronous motors of the motor generator sets by double throw oil switches. One position of these latter switches is for starting the sets and the other is the running position.

The motor generator sets consist of three units, a synchronous motor in the middle direct connected to and driving two direct current generators, one each side of the synchronous motor. Each generator is designed to give 1500 volt direct current and the two generators are connected in series to give 3000 volts for the trolley.

The fields of the synchronous motor are excited from a direct connected exciter on one end of the set and the fields of the direct current generators by an exciter on the other end of the set.

The direct current generators are connected to the trolley bus by means of air break switches and automatic circuit breakers mounted above the switchboard panels. There is a switch and circuit breaker for each unit and also for each feeder, of which there are generally two, one running east and one west, tapping into the trolley about every 1000 feet. In addition to the circuit breakers on the switchboard there is also a special high speed circuit breaker in the negative return circuit which inserts a resistance in circuit when it opens, thereby reducing the current in the circuit before the main switchboard breakers open, thus preventing arc overs and burning of contact points.

Contact making wattmeters, motor operated rheostats, relays, etc., forming part of the power limiting system described elsewhere, are located in the motor generator room of the sub-stations. Likewise space is provided in motor generator room for the 4400 volt signal transformers.

(8) Lightning Protection:

The high tension transmission lines are protected by one electrolytic lightning arrester per sub-station connected to the high tension bus. A similar type of arrester is used for each positive generator and feeder conductor and the same thing applies to the locomotives, but there are no other arresters on the trolley line. The supplemental ground feeder which is carried on the trolley poles above the trolley affords protection from lightning disturbances.

(9) Catenary Suspension for the Working Conductor:

The messenger is one-half inch diameter galvanized high strength steel seven strand cable supported on bracket type of construction by means of a porcelain insulator mounted on a metal pin attached to upper side of bracket. In span construction the messenger is attached to the span wires, which are insulated from the poles by means of two insulators in series on each side, between the pole and the nearest messenger and trolley wire. The two 4/0 hard drawn, copper trolley wires, located side by side, are supported from messenger by means of hangers of different lengths alternately attached to either trolley wire every seven and one-half feet.

(10) Working Conductors:

The working conductors are normally continuous from one sub-station to the other. The positive conductors consist of one 500,000 cir. mils copper feeder cable, two 4/0 trolley wires and one ½-inch steel messenger cable above described. On heavy mountain grades, or about 15 per cent. of the line, an additional 500,000 cir. mils or 700,000 cir. mils cable is used. The supplement feeder is tapped to the trolley wires at intervals of 1000 feet.

(11) Sectionalizing Switches:

The feeder and working conductor wires are sectionalized at the beginning and end of every passing track by means of section switches of standard type mounted on poles. These switches are normally kept in a closed position. In case of line trouble, however, they are used to isolate the short sections in trouble until such time as repairs can be made.

(12) Return Circuit:

The return circuit consists of 85 or 90 lb. track rails with joints bonded in the usual manner and an auxiliary 4/0 A. w. g. copper strand cable attached to the poles above the other wires and serving also as a ground wire. This auxiliary feeder is connected to the reactance bonds about every 8000 feet. It is of advantage not only from the standpoint of supplementing the return circuit but also in the interest of safety, in that it serves as a temporary shunt circuit to the rails in case of defective bonds or other failures in the rail circuits. In addition, it affords requisite protection against lightning, as there are no lightning arresters on the line between sub-stations. Both rails of main line track are bonded and also one rail of side tracks. One 250,000 cir. mils bond per joint is used except where mountain grades exceed 1 per cent., when an additional bond of the same capacity is used at each joint. Aside from the reactance bonds, which are installed for the signaling system, no cross bonds are used.

(13) Drop in Potential:

The maximum voltage drop is dependent upon the load and at times amounts to approximately 600 volts. The average drop is much less.

(14) Maintenance and Emergency Crews:

The overhead construction in the electrified territory (438 miles) is maintained by a force of 3 crews located at different points on the line and provided with work trains. There are 10 men in each crew, as follows:

1 foreman
2 linemen
1 groundman
1 engineman
1 fireman
1 conductor
2 brakemen

Two men are assigned to the testing of rail bonds. The regular maintenance and renewal of bonds is taken care of by the track section gangs.

(15) Special Features:

In general the construction of the distribution line does not differ materially from that of other direct current electric traction and trolley lines throughout the country aside from certain special features, as follows:

(a) Catenary construction, with two trolley wires hanging side by side and supported by messengers.

(b) Higher direct current voltage.

(c) Joint use of ground wire and supplemental return circuit.

The introduction of two trolley contact wires which hang side by side and are alternately supported from the messenger by means of hangers every seven and a half feet is a new arrangement. The second trolley conductor has the effect of increasing the area of contact with the locomotive pantagraph shoe approximately 100 per cent. and the method of staggering the supporting hangers insures continuity of contact. Both trolley wires serve as part of the positive feeders and together with the messenger cable are tapped to the supplement feeder attached to the supporting structure every 1,000 feet so that the increased area of contact and flexibility is obtained without detriment from the standpoint of strength and conductivity.

The voltage of the trolley (3,000 volts) is higher than that formerly used for direct current distribution. This feature, coupled with the double trolley wire and twin shoes on the pantagraph, has eliminated the sparking at the point of contact.

The introduction of the high voltage d-c. trolley permits of greater separation of power sub-stations than would be the case with lines of lower voltage.

(16) Passenger and Freight Locomotives:

The electric locomotives for passenger and freight service on the electric zone are of identical design, except that the passenger locomotives are equipped with oil fired flash boilers, oil and water tanks, etc., for heating coaches and are geared for higher speed than the freight locomotives. The complete locomotive is composed of two half units, each unit consisting of a cab mounted on two driving trucks. The frame of one truck is extended and carries the center pin for the guiding truck and the draft rigging. The figure shows an outline of one unit of a passenger locomotive and the location of apparatus in the cab.

C. M. & ST. P. RY.—ELECTRIC LOCOMOTIVES

TYPE	PASSENGER	FREIGHT	SWITCHING
Classification	444444	444444	404
Total weight	602,000	576,000	143,000
Weight mechanical equipment	354,000	328,000	85,000
Weight electrical equipment	248,000	248,000	57,500
Weight on guiding wheels	....	....	....
Weight on drivers	475,500	450,000	143,000
Tractive effort for starting	136,000	136,000	42,000
Tractive effort, 1 hr. rating	45,200	85,000	18,400
Tractive effort, continuous	38,000	71,000	13,500
Miles per hour, 1 hr. rating	28.5	15.25	12.0
Miles per hour, continuous rating	29.6	15.75	13.2
No. of motors	8	8	4
Type of motors	GE-253-A	GE-253-A	GE-255
Voltage	1500/3000	1500/3000	1500/3000
Gearing	82/18	71/29	64/17
Length over all	112′ 0″	112′ 0″	41′ 5″
Total wheel base	102′ 8″	102′ 8″	30′ 4″
Rigid wheel base	10′ 6″	10′ 6″	8′ 0″
Diameter of guiding wheels	36″	36″	....
Diameter of drivers	52″	52″	40″

There were furnished for this electrification of 440 miles between Harlowton and Avery 30 electric freight locomotives, 12 electric passenger locomotives and two electric switchers. Two more electric switchers of the same design as originally furnished have recently been delivered.

A comparison of the characteristics of the principal type of steam locomotives used previous to the electrification is shown on the figure and tabulated below.

C. M. & ST. P. RY.—COMPARATIVE STEAM LOCOMOTIVES

DESIGNATING LETTER	F	K	L	N	I
Type	Pass.	Freight	Freight	Helper	Switch
Classification	4-6-2	2-6-2	2-8-2	2-6-6-2	0-6-0
Wt. engine and tender	385,250	360,000	414,500	555,700	158,000
Wt. tender	134,550	154,000	154,000	165,700	55,000
Wt. on guiding wheels	46,000	22,000	25,500	20,500	....
Wt. on trailing wheels	42,700	32,000	34,000	46,000	....
Wt. on drivers	160,100	152,000	201,000	323,500	103,000
Tractive effort lbs	36,500	33,300	46,630	76,200	23,800
T. E. % wt. on drivers	22.7	21.9	23.2	23.5	23.1
Diameter cylinders	23″	21″	24″	23½x37″	18″
Stroke	28″	28″	30″	30″	24″
Boiler Pressure	200	200	200	200	180
Heating Surface, sq. ft	....	2,348	3,614	6,554.6	1,312
Grate area, sq. ft	48.8	45.0	48.8	72.4	22
Length over all	78′ 4¼″	70′ 8¼″	76′ 7¼″	90′ 1¼″	52′ 2¼″
Total wheel base (eng.)	35′ 7″	29′ 3″	35′ 1″	48′ 0″	11′ 0″
Rigid wheel base	14′ 0″	11′ 0″	16′ 6″	10′ 0″	11′ 0″
Diameter guiding wheels	36″	33″	33″	33″	....
Diameter trailing wheels	43″	43″	43″	43″	....
Diameter drivers	69″	63″	63″	57″	50″
Tender capacity, gallons	7,000	8,000	8,000	9,000	2,900
Tender capacity, tons	10	14	14	14	4

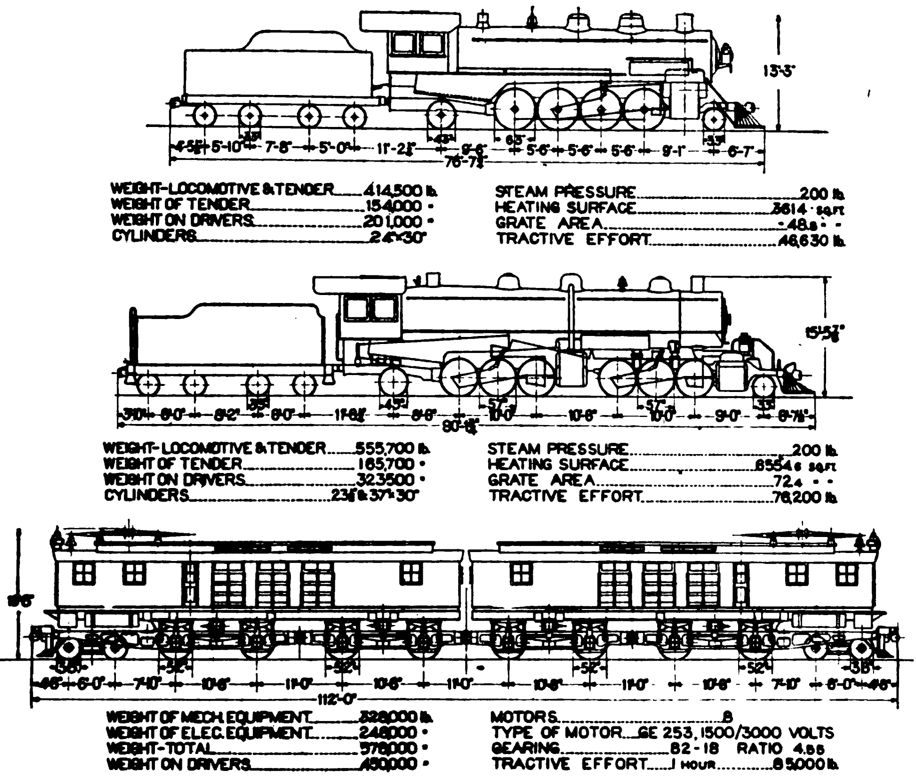

FIG. 1.—PRINCIPAL TYPES STEAM AND ELECTRIC LOCOMOTIVES, CHICAGO, MILWAUKEE & ST. PAUL RAILWAY.

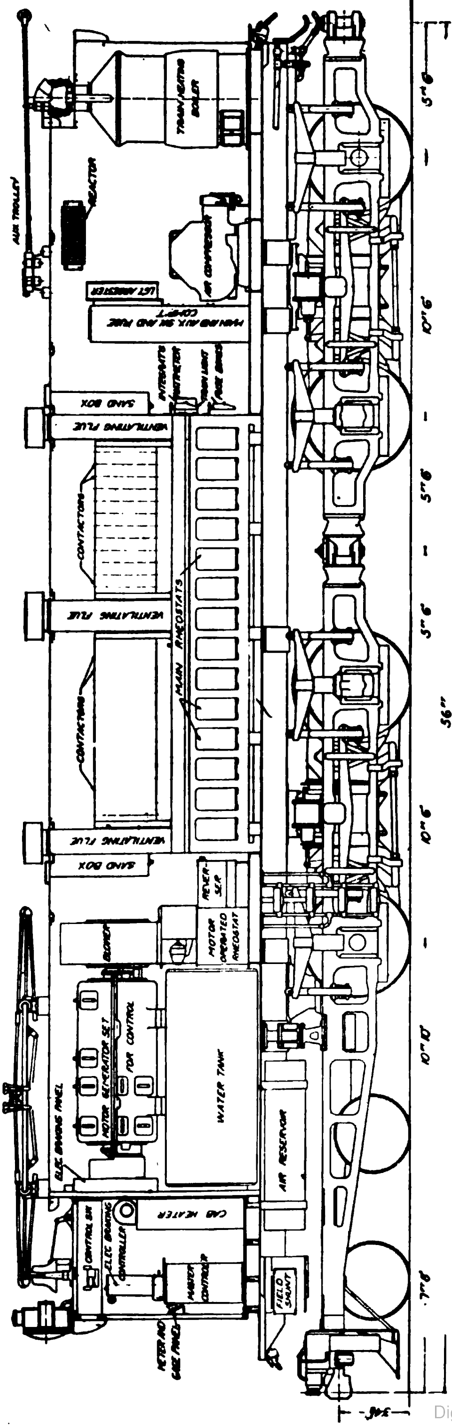

FIG. 2.—OUTLINE OF ONE-HALF OF A PASSENGER LOCOMOTIVE.

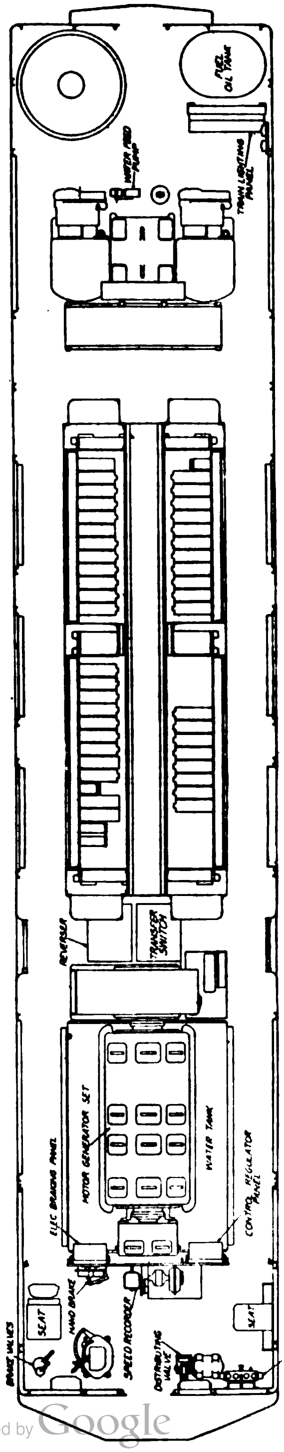

FIG. 3.—LOCATION OF APPARATUS IN ONE-HALF PASSENGER LOCOMOTIVE.

(17) Switching Locomotives:

All the weight—70 tons—is on the drivers. The motors are geared to the driving axles by single gears. There are two master controllers in the control cab so that engineers may use either position when operating in yards. Many of the parts of these locomotives, such as air compressor, small switches, headlights, etc., are interchangeable with the same parts on the main locomotives.

(18) Signal System:

A complete description of this signal installation will be found in the Railway Signal Engineer of September, 1917, Volume 10, No. 9, pages 256 to 262, inclusive.

The type of trolley pole construction prohibited the use of upper or lower right-hand quadrant semaphore signals, as either of these types would have been obstructed from view by the poles. It was necessary, therefore, to install either upper or lower left-hand quadrant signals or light signals. On account of the simplicity of construction and operation of the light type of signals which eliminated all moving parts, the light type was installed.

The initial cost of an a-c. signal installation for electric traction will exceed an equivalent signal installation of direct current by approximately 35 per cent. when the overhead structure is available for the support of the necessary signal conductors.

In general the operation cost will be considerably less in an a-c. light signal installation than in a direct current semaphore installation, mainly because of the economy in the use of a-c. power as against d-c. power, which is due, first, to the lower cost of a-c. power as compared with d-c. power, and second, on account of the large decrease in the labor charges in handling the a-c. as against the d-c.

Climatic and other conditions being favorable, the simplicity in the apparatus of an a-c. signal system, particularly when the light type of signal is used, permits of assigning much longer sections to a given maintenance force than is possible in the d-c. systems, resulting in a marked decrease in maintenance costs.

(19) Electrical Interference:

There has been no marked interference in the talking system by the propulsion system. The Engineers of the A. T. & T. Company have made some study on the ground and found slight interference from so-called tooth-ripples of some thirteen hundred cycles. Experiments have indicated that the installation of resonant shunts in the sub-stations will remove the trouble.

The Telephone Company offered no further specific complaint. It was indicated that they would desire transposition in the 110,000 volt line. The railway desires specific cases of interference and information to show that transpositions will remove any interference alleged to exist which is the present status.

(20) Safety Appliances:

The usual "Danger" signs were placed in conspicuous places in the locomotives, in sub-stations, power stations and on some poles of the transmission line. "Danger" signs are placed on the tops of the locomotives near the ladders. Instructions to cover resuscitation of the person shocked were posted in conspicuous places in the locomotives and in sub-stations and power stations.

High tension contact points in the locomotives were all enclosed, and in some cases, in addition to the doors giving access to high tension contact points, switches were so placed that they would have to be thrown to cut off the power before access was given. A special set of instructions cautioning the employes in handling the apparatus was posted in every locomotive cab. Access to brushes of some motors and generators was given through spring doors only.

All high tension contact points in the sub-stations were either out of normal reach or inclosed. Some machines were protected with wire cages with access through doors only.

All high tension contact points in the power stations were either out of normal reach or inclosed. Special "Danger" tags with complete information relative to time of disconnecting and with authority for same were placed on control board switches opened for some particular purpose. In closing the switch, tag record covering time of closing and authority for same was entered on the tag and the tag was then filed.

A large part of the maintenance work on the trolley wire was handled with properly insulated cars and without cutting off power. In working on dead trolley sections, the dead section was grounded to give protection should the power be put on without authority.

Specific information as to accidents which had occurred was not available, but it was stated that but one employe had been killed, and this through disobedience of orders. It is further stated that no passengers had been injured, but that some trespassers had met with accidents due to attempting to ride the tops of the locomotives.

(21) Changes in Track Arrangement:

No particular changes were necessary on account of the introduction of electrification in the arrangement of buildings or tracks, but the fact that two electric locomotives could handle a 2800 ton train necessitated the lengthening of all the passing tracks to 1000 feet each. On the .4 per cent grades 5000 ton trains are handled.

(22) Discarded Steam Equipment and Property, Etc.:

In the case of this electrification, the discarded steam equipment and property was of comparatively small importance, on account of the ability to transfer the 112 steam locomotives to other divisions where they filled existing deficiencies. It was not possible to discard any material portion of the old shops on account of the necessity of overhauling steam equipment there. The consolidation of the four operating districts into two dispensed with two complete engine terminals and several water stations where pumping had been resorted to. The gravity water stations have been retained and engine terminals have not been entirely dismantled. Fuel stations have also been abandoned and demolished.

(23) Power Indicating and Limiting Equipment:

Under the terms of their contract with the Montana Power Company, the railway considered it necessary to install a power indicating and limiting system in order to automatically prevent excessive peak demands for power and as guide for the train dispatcher. This system is now in operation over the 220 miles of the Rocky Mountain Division where there are five feeding in points with the Montana Power Company. The system was designed and installed to accomplish the following results:

(1) Indicate the total power (kilowatts).

(2) Record the total power on curve-drawing watthour meter supplied by the Power Company.

(3) System to automatically take care of certain amount of power (specified by railway) returned to power company's lines due to regenerative braking features on the locomotive.

(4) Protect each substation against excessive overloads.

(5) Limit total power demand on the power company to an adjustable predetermined amount.

(6) Reduce the direct current voltage of the substation when load exceeded the peak limit decided upon, reducing the voltage of the sub-stations with greatest load first, following with sub-stations with less load. Sub-stations with less than half load or some predetermined load not to be affected. At present the system is so connected that the voltage of all sub-stations is reduced simultaneously so as to get the benefit of as much reduction as possible under any given load conditions.

(7) Manual means by which the total resistance of the pilot wire circuit could be easily and instantly adjusted at the dispatcher's office to compensate for variations in resistance due to temperature changes.

(8) Accomplish the purpose outlined above with power supplied to railway's 100,000 volt transmission line at five feeding in points distributed along the 200-mile division.

(24) Apparatus:

The power limiting and indicating system is composed of two parts, one part consisting of apparatus located in the dispatcher's office and the other part of apparatus in the sub-stations. The two parts are connected by a metallic circuit or pilot wires.

The function of the apparatus in the sub-stations is to measure the power input to the motor generator sets and also the amount of power regenerated. This feature is accomplished by contact making wattmeters, which cut in and out resistance in the pilot wire circuit (the greater the power delivered by the Power Company the greater the resistance cut in the circuit). There is a contact making wattmeter in each of the five substations which are connected directly with the Montana Power Company's lines and the resistances which these meters control are all in series so that the total resistance inserted in the pilot wire circuit is a measure of the total kilowatt delivered to the system.

A small motor generator set in the dispatcher's office energizes the pilot wire circuit and by means of a Tirrel regulator constant voltage can be held across the pilot wires for any setting desired. The current in the pilot wire will vary whenever the contact making wattmeters cut resistance in and out of the pilot wire circuit. Hence by properly calibrating the instruments which are direct current ammeters the variations of the current in the pilot wire can be made to indicate kilowatts. One of the instruments is an indicating meter which can be seen from the dispatcher's desk and the other is a recording meter which uses the tapalog principle to give a graphic record of the power input to the Rocky Mountain Division.

In addition to the contact making wattmeters in the substation there is a relay for each motor generator set; these relays make contact when the current in the pilot wire drops to .237 amperes. When these relays make contact a motor driven rheostat cuts resistance in the fields of the direct current generators and lowers the voltage of the trolley, slows down the trains and thereby limits the power taken. The maximum voltage reduction which can be obtained in this manner is 30 per cent. or a trolley voltage of 2100. Further reduction if necessary is obtained through instructions to freight enginemen to notch back into series whenever very low voltage is indicated by the voltmeter in each locomotive cab.

The method used in adjusting for various peak loads at which these relays make contact and limit the power is by raising the voltage across the pilot wire. The higher the voltage across the pilot wire the greater the resistance which has to be inserted to bring the current in the pilot wire below .237 amperes at which point the relays make contact, or, in other words, it requires more kilowatts to increase the resistance in the pilot wire to a point where the relays cut in and start the motor operated rheostats in circuit with the generator fields.

In order that the wattmeters will indicate the correct power input regardless of the voltage on the pilot wire there is an adjusting resistance for the meters which is interlocked with the rheostat controlling voltage regulator.

The pilot wire circuit is calibrated daily to compensate for temperature changes. This is accomplished by reversing the current in the pilot wire, thereby short circuiting the wattmeter resistances in the substations by means of reverse current relays and then adjusting the resistance of the pilot wire circuit to 2000 ohms; that is, with 1200 volts across the pilot wires adjust the resistance so that .6 amperes will be read on the switchboard meter. There is an adjustable rheostat on the switchboard in the dispatcher's office for this purpose.

(25) Results of Preliminary Operation:

The amount of power transferred between Power Company's line over the railway's transmission line often exceeded capacity limits provided.

With present service and somewhat low setting of protective relays and circuit breakers in substations, advantage could not be taken of the three times load limiting device designed to maintain constant load above this point and, for the present, this equipment is not used.

In order to obtain maximum possible peak reduction, selective coil on contact-making ammeter relay was disconnected and half load limit removed.

The following modifications have been made: On the Rocky Mountain Division with five feeding in points there was an unavoidable transfer of large blocks of power over the railway company's transmission line, hence it was decided to operate the contact making wattmeters originally controlled by current transformers in the incoming lines of the Power Company to transformers in the motor generator circuits and arbitrarily allow for losses in the step down transformers. The device would thus be unaffected by transfer of power which came in over the Railway Company's lines and left over the Power Company's lines, but corrected for power regenerated by trains and returned to Power Company's lines.

Three times load limit removed temporarily.

Selective equipment and underload limit removed for the present.

(26) Power Saved:

The power indicating and limiting system is as yet in operation only on the Rocky Mountain Division. Operation of this system on the Missoula Division, power for which is supplied under a separate contract, will probably commence with the beginning of the new year. Inasmuch as the minimum cost of power to the railway company is based on the maximum demand, it is evident that with the 30 per cent. reduction obtainable as above referred to a very great saving in the cost of power results to the railroad. The system was put into operation about the beginning of July, 1918, with a kilowatt setting of approximately 12,000. On April 1, 1919, this setting was increased to 14,000 kilowatts. Without the limiting feature of the power indicating and limiting systems, the demand would probably run to not less than 20,000 kilowatts.

(27) New Duties of the Train Dispatcher:

In order to obtain a favorable contract for electric power the maximum demand for power must be kept as low as it is practical to make it. For this reason a power indicating and limiting equipment is required for the purpose of indicating to the dispatcher the amount of power taken, and also for limiting the power to a predetermined amount. By the aid of this equipment the dispatcher regulates the dispatching of trains so as to avoid exceeding the predetermined amount of power agreed upon by the railway company and the power company. That is, the dispatcher sees to it that trains are not dispatched in a way that two or more trains are ascending the heavy grades at the same time, but will endeavor to dispatch them in a manner that permits one train to ascend the heavy grades while another is going down. Should the dispatcher err in this respect then the power limiting feature comes into play and automatically limits the power by slowing up the trains. A chart showing the power required for trains of different tonnage at all points on the district is posted in the Train Dispatcher's office to enable him to become familiar with the loads so that he can handle them promptly and provide the proper intervals between trains so as to avoid bringing the power limiting features into play. The higher the power limiting feature is set the easier it is to dispatch trains, but the power costs are correspondingly increased. The lower the power limiting feature is set the more difficult it becomes to dispatch trains in a manner which will prevent the slowing down of trains and running into overtime for the crews. Thus it becomes the duty of the train dispatcher to keep in mind not only the train movements, but also to regulate movements so that the power costs and overtime of crews will be a minimum. With a little study of train operations and a little practice the dispatchers are able to adjust the train movements to the needs of the service.

(28) Capital Cost:

The table below gives a condensed grouping of items which are included in the capital cost of the electrification.

Items Included in Capital Cost of Electrification.

440 miles first track electrification on wood poles.
147 miles other tracks, passing sidings, yards and spurs.
587 miles track bonding.
371 miles single conductor in three phase 100,000 volt transmission line.
14 sub-stations aggregate capacity 59,500 kw.
Engineering, signals, miscellaneous, etc.
Total (approximately)....................................$7,250,000
12—300-ton electric passenger locomotives.
30—288-ton electric freight locomotives.
*3— 70-ton electric switching locomotives.

*45 Total electric locomotives (approximately)...........$5,500,000
Less value of steam equipment replaced (estimated)........ 2,500,000

Additional capital cost, account electrification..............$10,250,000

* Includes one 50-ton, 1500-volt locomotive at Great Falls not part of main line electrification.

The above capital cost covers a plant which is handling a greater tonnage than was previously handled by steam locomotives and the indications are that there is margin in the equipment supplied to handle a still greater tonnage.

STEAM LOCOMOTIVES REPLACED BY ELECTRIC LOCOMOTIVES

	No. of Locomotives	Avg. Wt. on Drivers, Lbs.	Avg. Wt. Engine, Lbs.	Avg. Wt. Tender, Lbs.	Total Wt. Engine and Tender, Lbs.
PASSENGER:					
Rocky Mt. Division	12	153,860	233,400	141,220	374,620
Missoula Division	7	149,440	229,130	126,470	355,600
Total Steam	19	152,200	231,800	135,600	367,600
Total Electric	12	475,500	....	....	602,000
FREIGHT:					
Rocky Mt. Division	50	230,720	291,270	158,140	449,410
Missoula Division	35	173,330	229,680	155,340	385,020
Total Steam	85	207,090	264,720	157,000	421,720
Total Electric	30	450,000	....	....	576,000
SWITCHING:					
Rocky Mt. Division	5	127,000	127,000	110,400	237,400
Missoula Division	3	127,000	127,000	110,400	237,400
Total Steam	8	127,000	127,000	110,400	237,400
Total Electric	2	140,000	....	....	140,000
TOTAL:					
Rocky Mt. Division	67	14,016,420	17,999,320	10,153,520	28,152,840
Missoula Division	45	7,993,230	10,023,880	6,653,320	16,677,200
Total Steam	112	21,509,650	28,023,200	16,806,840	44,830,040
Total Electric	44	19,486,000	....	....	24,781,000

Estimated purchase price steam locomotives, .09x28,023,200—$2,500,000 approximately.

The value of steam equipment replaced represents approximately the cost of 112 steam locomotives which were assigned to the Rocky Mountain and Missoula Divisions prior to electrification taken at 9c per lb. (wt. of engine). This is hardly a fair comparison between steam and electric for the reason an additional investment would have had to be made in any event, in order to handle the increase in tonnage since electrification was begun. That is, if electrification had not been adopted, the 112 steam locomotives could not have been taken from the Rocky Mountain and Missoula Divisions and placed in operation elsewhere but their equivalent would have had to have been purchased new to do the work that they are doing on other divisions and in addition more locomotives would have been required for the increased service on the Rocky Mountain and Missoula Divisions. At the time the investment was made for electrification steam locomotives were selling at 13-15c per lb., hence the investment in steam equipment which was avoided by the adoption of electric operation is easily twice the value assumed for steam equipment replaced. To attempt a comparison on this basis and estimate the additional equipment and track facilities required for steam operation would necessitate a very careful study of previous steam operation, supplemented by many assumptions as regards what might be done in case of steam operation, such as improvements in operating methods, possible changes in grade, double tracking, etc.

(29) Comparative Operating Results:

Mr. B. Beeuwkes, Electrical Engineer of the Chicago, Milwaukee & St. Paul Railway, in his paper before the New York Railroad Club, March, 1917, compares three months' steam operation with three months' electric operation before the power limiting and indicating device was installed. The following table is abstracted from Mr. Beeuwkes' paper:

COMPARISON STEAM AND ELECTRIC OPERATION—FREIGHT

	OCTOBER		NOVEMBER		DECEMBER		TOTAL	
	Steam	Elect.	Steam	Elect.	Steam	Elect.	Steam	Elect.
1,000 ton miles	98,512	125,522	93,228	130,848	91,122	107,717	282,862	364,087
Train miles	60,666	65,400	58,014	63,299	58,257	57,311	176,937	186,010
Ton mi. train mi	1,625	1,970	1,605	2,070	1,563	1,880	1,600	1,960
Total time hrs	6,094	5,022	5,946	5,084	5,785	4,429	17,825	14,535
No. of trains	535	585	523	583	526	543	1,584	1,711
Hrs. per train	11.29	8.59	11.26	8.72	10.99	8.16	11.25	8.50
Mins. per 1,000 T. miles	3.70	2.40	3.83	2.23	3.81	2.47	3.78	2.39

For the same tonnage hauled over the Rocky Mountain Division electric operation has effected a reduction of 22.5 per cent. in the number of trains, 24.5 per cent. in the average time per train and has improved operating conditions so that nearly 30 per cent. more tonnage can be handled by electric operation in about 80 per cent. of the time it formerly took to handle the lesser tonnage by steam operation. This means a valuable increase in the single track capacity of the line.

Comparative Operating Expenses: In January, 1917, the Government took over the operation of the railroads and the Adamson Eight-Hour Law went into effect. Later new wage scales were allowed the shop forces, trackmen, etc., and prices for materials and supplies were continually being adjusted. As a result of these conditions any comparison of present electric operating costs with steam prior to January 1, 1917, is subject to very considerable corrections to bring the steam expense to the same basis of costs as the electric. The corrections are so numerous and subject to so many interpretations that the real facts cannot be made sure of at the present time. It is possible, however, to obtain from the annual operating statements certain operating costs which in many cases may serve as a guide in forecasting what economies may be obtained by the substitution of electric operation for steam. For this purpose the following table was compiled:

ELECTRICAL OPERATING COSTS

From Annual Reports to Stockholders

	1917 12 months	1918 12 months	AVERAGES PER YEAR 1917 and 1918
MAINTENANCE OF WAY AND STRUCTURES			
Power Substation buildings	$ 468.64	$ 622.38	$39.00 per substation.
Power transmission systems	1,000.68	4,265.44	$7.10 per mi. trans. line.
Power distribution systems	81,944.74	73,277.70	$134.00 per mi. track.
Power lines poles and fixtures	14,572.92	20,810.72	$40.20 per route mile (440).
MAINTENANCE OF EQUIPMENT			
Power Substation Apparatus	$ 10,034.37	$ 25,914.23	$1,281. per substation.
Other locomotive repairs	220,525.76	236,906.35	0.1023 per loco. mile.
Other locomotive depreciation	77,134.23	85,208.51	0.0363 per loco. mile.
TRANSPORTATION			
*Yard switching power produced	$ 233.83		
*Train power produced	49,402.15	$ 94,580.46	$5,151. per substation.
Yard switching power purchased	8,321.86	12,230.88	
Train power purchased	544,224.25	683,997.96	
Yard motormen	$ 16,007.63	$ 23,084.87	
Train motormen	262,177.75	346,260.32	

*Sum of these two items represents mainly substation attendance.

The Effect of Electric Operation on Track and Rails: The consensus of opinion of the Roadmasters and Superintendents on the electrified zone is that there is no more slipping of the locomotive wheels on the rail and consequently no more damage to the top of the rail under electric operation than there is with steam locomotives. It has not been found that there is any greater tendency for the rails to creep on account of regenerative braking on descending grades than there was under the braking action of steam locomotives. No case has been found where electric locomotives moving at a high rate of speed have tended to displace the rail on the ties or the ties in the ballast. Roadmasters agree that the electric locomotive is easier on the track than steam locomotives because of the less rigid construction. It is stated that the flange wear on curves under electric operation is actually less than under steam operation for the reason that the electric locomotives are less rigid in their wheel arrangement than the steam locomotive. On curves the outer rails are elevated for thirty miles per hour on mountain grades and for forty-five miles per hour for valley territories. On the Rocky Mountain and Missoula Divisions the mountain grade superelevation is one-half of one inch to one degree of curvature with a maximum of three inches. On other curves the superelevation is one inch per degree with a maximum of three and one-half inches.

(30) Relation of Electric Power Consumption to Coal Consumed:

The following figures are obtained from Mr. Beeuwkes' paper, the coal consumption being for October, November and December, 1915, and the electric energy consumption for the corresponding months of 1916.

ITEMS	OCTOBER		NOVEMBER		DECEMBER		AVERAGE	
	Steam	Elect.	Steam	Elect.	Steam	Elect.	Steam	Elect.
*Kw-hr. per train miles, passenger	....	30.3	....	27.4	....	29.9	....	29.1
Lbs. coal per train mile, passenger	171	....	201	....	193	....	188	....
Ratio lb. coal/kw-hr.	5.65	....	7.34	....	6.46	....	6.46	....
*Kw-hr. per 1,000 ton mile freight	....	37.4	....	39.1	....	42.0	....	39.4
Lbs. coal per 1,000 ton mile, freight	247	....	294	....	291	....	276	....
Ratio lb. coal/kw-hr.	6.61	....	7.52	....	6.93	....	7.01	....

*Electric power measured on Power Company's meters in the high tension side of the step down transformers in the substations.

The results indicate that one kw hr. measured at the low tension side of the transformers in the sub-stations is equivalent to 7 pounds of coal on the tender of a steam locomotive.

On the basis of the above relationship the ratios of power expense to coal expense for various prices of power and coal have been computed and are given in the table on opposite page.

(31) Application of the Electrification of the Chicago, Milwaukee & St. Paul Railway to Other Railroads:

In a very general way, the following statements can be made regarding the utilization of water power for the electric operation of other railroads:

First: That 110,000 volts transmission of electric power, with 3000 volts on the trolley wire, are practicable and reliable voltages for electric railroad service for 100 miles or more of single track.

Second: That such a system of electric operation will increase the capacity of a railroad from 25 to 35 per cent.

Third: That such a system of electrification will probably prove economical as compared with steam operation, when the cost of reliable electric power and coal bear the relation one to the other that they do in the preceding table, as shown above the diagonal line, provided the railroad traffic is favorable for electric operation.

Fourth: The introduction of electric locomotives equipped with electric brakes has made possible the haulage of heavier trains at higher speeds on heavier grades, such as mountain divisions, with greater safety and reliability under all climatic conditions.

Ratio Electric Power Expense to Fuel Expense
for
Various Prices of Coal and Electric Power
Based on 1 Kwh Substation Input being Equivalent to
7 Pounds Coal on Tender of Steam Locomotives

Price of Coal 2000 lb.	Price of Power Cents per Kwh														
	.525	.700	.875	1.050	1.225	1.400	1.575	1.750	1.925	2.100	2.275	2.450	2.625	2.800	2.975
$8.50	176	235	294	353	412	.471	529	.588	.647	.706	.765	.824	882	.941	
8.00	.188	250	313	375	438	.500	.563	.625	.688	.750	813	.875	.938		1.063
7.50	200	267	.333	.400	467	.533	.600	.667	.733	.800	.867	.933		1.067	1.133
7.00	214	.286	.357	.429	.500	.571	.643	714	786	.857	.929		1.071	1.143	1.214
6.50	231	.308	385	462	538	.615	.692	.769	.846	.923		1.077	1.154	1.231	1.308
6.00	.250	.333	.417	.500	.583	.667	.750	.833	.917		1.083	1.167	1.250	1.333	1.417
5.50	.273	.364	.455	.546	636	.727	.818	.909		1.092	1.182	1.273	1.364	1.455	1.545
5.00	.300	.400	.500	.600	700	.800	.900		1.100	1.200	1.300	1.400	1.500	1.600	1.700
4.50	.333	.444	.556	.667	.778	.889		1.111	1.222	1.333	1.444	1.556	1.667	1.778	1.889
4.00	.375	.500	.625	.750	.875		1.125	1.250	1.375	1.500	1.625	1.750	1.875	2.000	2.125
3.50	.429	.571	.714	.857		1.143	1.286	1.429	1.571	1.713	1.857	2.000	2.143	2.286	2.429
3.00	.500	.667	.833		1.167	1.333	1.500	1.667	1.867	2.000	2.167	2.333	2.500	2.667	2.833
2.50	.600	.800		1.200	1.400	1.600	1.800	2.000	2.200	2.400	2.600	2.800	3.000	3.200	3.400
2.00	.750		1.250	1.500	1.750	2.000	2.250	2.500	2.750	3.000	3.250	3.500	3.750	4.000	4.250
1.50		1.333	1.667	2.000	2.333	2.667	3.000	3.333	3.667	4.000	4.333	4.667	5.000	5.333	5.667

Note: Diagonal Line indicates for what Prices of Coal and Electric Power the Expense is Identical

Appendix E

(ITEM 7) ELECTRICAL INTERFERENCE

A. H. Armstrong, *Chairman;*
H. K. Lowry, *Vice-Chairman;*
R. H. Ford,
J. B. Savage,
M. Schreiber,
F. E. Wynne.

Sub-Committee.

(1) Electrical Interference with Communication Circuits by Electric Railway Propulsion Currents:

It is recognized that electric railway propulsion currents flowing through an overhead trolley with its supplementary feeders and completing the circuit through the track rails and ground return may cause interference with the operation of neighboring telephone and telegraph circuits, unless proper steps are taken to minimize such interference. It is the purpose of this report to briefly outline the magnitude of this problem and the reasonable safeguards that may be employed to minimize the trouble.

The Committee has no record of any existing interference of a serious nature with communication circuits by direct propulsion currents carried through a third rail and track return, and will therefore eliminate direct current third rail construction from the discussion, which will be confined to the effect of propulsion currents traversing a circuit comprising an overhead trolley and track return. This report does not include the subject of interference from transmission lines.

There are two general types of current employed for the propulsion of electric railway motors, alternating and direct, and the passage of such currents over the secondary or trolley circuits is so different in its effect on neighboring telephone and telegraph circuits that it is necessary to treat each as a separate problem.

(2) Alternating Current Interference:

Alternating current trolley wires carry either single phase or three phase current; in the latter case two overhead conductors are used in connection with the track return. The problem of interference of alternating currents with neighboring circuits is essentially the same in each case, requiring the same corrective measures, and in this report reference to alternating current trolley circuits will embrace all forms of overhead construction carrying either single phase or three phase current.

The interference with neighboring telephone and telegraph lines, caused by alternating current traversing an overhead trolley conductor with track return, may be serious without the introduction of devices or measures which will minimize its magnitude. This interference may be caused partly by the static charge induced on neighboring conductors by reason of the high voltage (11,000 to 15,000 volts) usually employed on alternating current trolleys, but is chiefly due to the magnetic effect of the alternating current flowing in the trolley-track circuit. The most severe of these disturbances are set up at times of abnormal conditions, such as extreme over-loads or short-circuits.

Inductive disturbance of alternating propulsion currents extends beyond the immediate vicinity of the railroad right-of-way, due to the fact that the track rails carry only a part of the return current and the distance between the overhead trolley and the equivalent ground center of the return circuit is much greater than the physical spacing of 18 to 24 ft. from trolley to rails. Experience gained in about 14 years of alternating current railway development has shown the desirability of adopting certain forms of construction which are known to minimize interference with neighboring circuits. Below is given a brief summary of corrective measures that are in use:

Measures That Are Employed to Minimize Telephone and Telegraph Interference by Alternating Propulsion Currents.

1. Neutralizing transformers in telegraph circuits.
2. Combination of coils and condensers commonly known as "resonant shunts" in telegraph circuits.
3. Balance and insulation of telephone circuits.
4. Frequent transformer substations feeding trolley and feeders in multiple.
5. Avoidance of stub end feed.
6. Sectionalization of propulsion circuits.
7. Auto-transformers, distribution system as installed on the N. Y. N. H. & H. R. R.
8. Track booster transformers.
9. Current limiting reactors.
10. Increase the separation of telephone and telegraph wires from the propulsion circuits.

All of the above measures and devices are now employed, some with greater degree of success than others. Placing telephone and telegraph wires in lead covered cables eliminates static voltages in communication wires but only slightly reduces magnetically induced voltages.

The situation as regards alternating current interference with neighboring communication circuits is summed up by H. S. Warren, of the A. T. & T. Co., in his paper of April 8, 1918, before the A. I. E. E. as follows:

"It may be said in conclusion that means are now known whereby alternating railway currents can be kept sufficiently within control, except under abnormal conditions, to prevent substantial interference to neighboring communication lines, although the application of such means to the extent necessary to produce satisfactory results may involve considerable expense.

"Even under abnormal conditions the interference can be greatly reduced by the application of suitable measures, but in some cases there still remains the problem of obtaining a sufficient reduction of interference without incurring a cost which the railroad companies consider excessive."

(3) Direct Current Interference:

Interference by direct current propulsion circuits with neighboring telephone circuits may be occasioned by ripples caused by tooth harmonics, and a further source of disturbance may be due to the short circuits inevitable in electric railway practice. Tooth harmonics may be minimized and practically eliminated by proper machine design in new installations and by the introduction of resonant shunts in the sub-stations of existing installations in instances where tooth harmonics are found to have any appreciable effect on neighboring telephone circuits.

The effect of direct current short circuits may be greatly reduced by the introduction of high speed circuit breakers now developed to operate with extreme rapidity and introduce a current limiting resistance before the current has had time to reach its full short circuit value. Another source of disturbance is the shifting of the earth potential due to excessive voltage drop in the rail circuit.

Tests were made upon the electrified lines of the Chicago, Milwaukee & St. Paul Railway for the French Electrification Commission the early part of this year, at which representatives of that railroad, American T. & T. Co. and Western Union Co. were present. These tests were made over a single electrified track extending 169 miles and the effects with normal operation and short circuit conditions were noted on the telephone and telegraph circuits paralleling the 3000 volt direct current trolley throughout its entire length.

In summarizing the results of this test, it can be definitely stated that there was no interference with the regular operation of the Helena-Spokane double multiplex printing telegraph circuit by reason of its being routed and parallel to and directly on the Chicago, Milwaukee & St. Paul Railway right-of-way for a distance of 169 miles, either from the normal operation of the electrified railroad system or from the application of short circuits to the system.

Measures That Are Employed to Minimize Telephone and Telegraph Interference by Direct Propulsion Currents.

1. Resonant shunts in existing substations when tooth ripples are sufficiently pronounced to cause interference.
2. Generators designed to give negligible tooth harmonics.
3. High-speed circuit breakers.
4. Reduce track circuit voltage drop.
5. Balance and insulation of telephone circuits.

In summarizing the effect of direct propulsion current, upon neighboring communication circuits, it may be stated in general that when such of the above means as are necessary are carefully applied no serious interference is noted.