Electric Power Consumption on the Rocky Mountain and Missoula Divisions of the C., M. & St. P. Rwy.*

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The figures presented in this article covering the operation of the electrified divisions of the C., M. & St. Paul Rwy. for the year 1919 should be carefully analyzed by railway executives and engineers. Volumes have been written and published to show the economy and other advantages of electrical operation of main line railways, specially over mountain grades, but no arguments for electrification on paper will carry the weight of conviction of actual performance. If the operation of our main line railways by electric power is ever to be an accomplished thing present experience would seem to indicate that it will be realized by means of high voltage direct current, and this fact gives added significance to the results obtained by the C., M. & St. Paul.—Editor.

Power for the electrical operation of the Chicago, Milwaukee & St. Paul Railway between Harlowton, Montana, and Avery, Idaho, is delivered to the transmission system in the form of 100,000-volt, three-phase, 60-cycle current. The power is supplied under two separate contracts, one for the Rocky Mountain division, extending from Harlowton to Deer Lodge, and the other for the Missoula division, extending from Deer Lodge to Avery.

The power company's 100,000-volt transmission lines are shown in the single line layout of the system, as are also the points of power delivery to the railway company and the latter's 100,000-volt transmission system.

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The railway transmission line of the Rocky Mountain division extends from Two Dot substation to the Morel substation, a distance of 184 miles, the former point being 12 miles from Harlowton, eastern terminus of the division, and the latter point 17 miles from Deer Lodge, the western terminus. Power is delivered by the power company at the Two Dot, Josephine, Piedmont and Morel substations. The railway transmission line of the Missoula division extends from Gold Creek substation, 18½ miles from Deer Lodge, a distance of 180 miles, to the substation at Avery, the western terminus of the division.

Seven substations on each division are used to convert the 100,000-volt alternating current of the transmission line to the 3000-

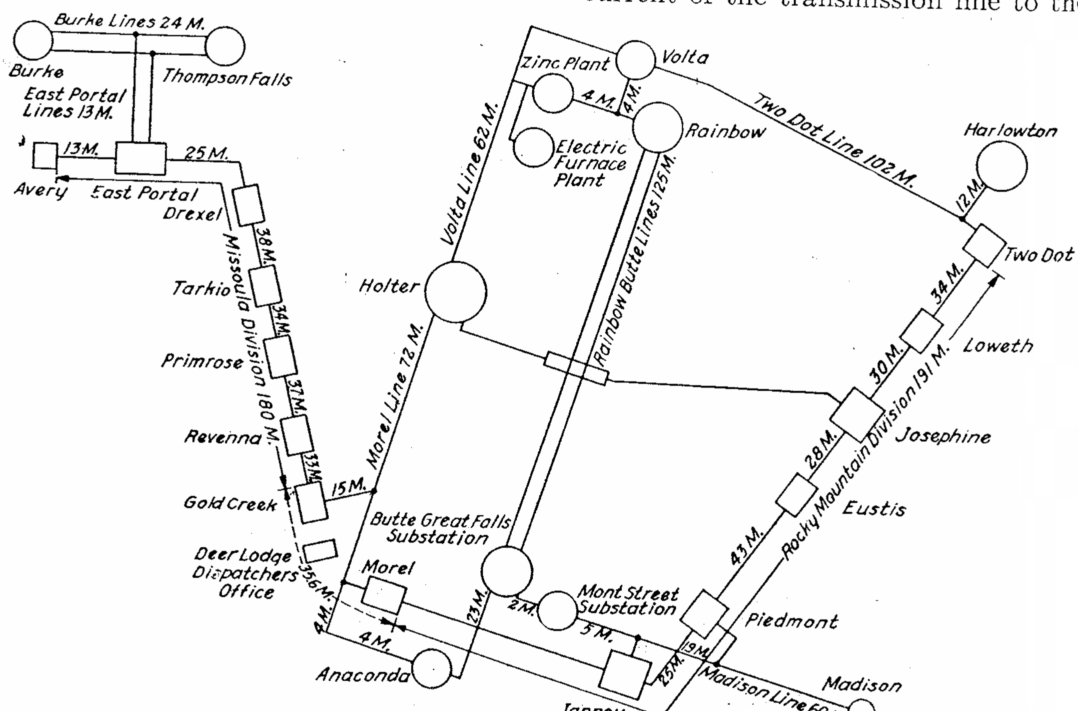
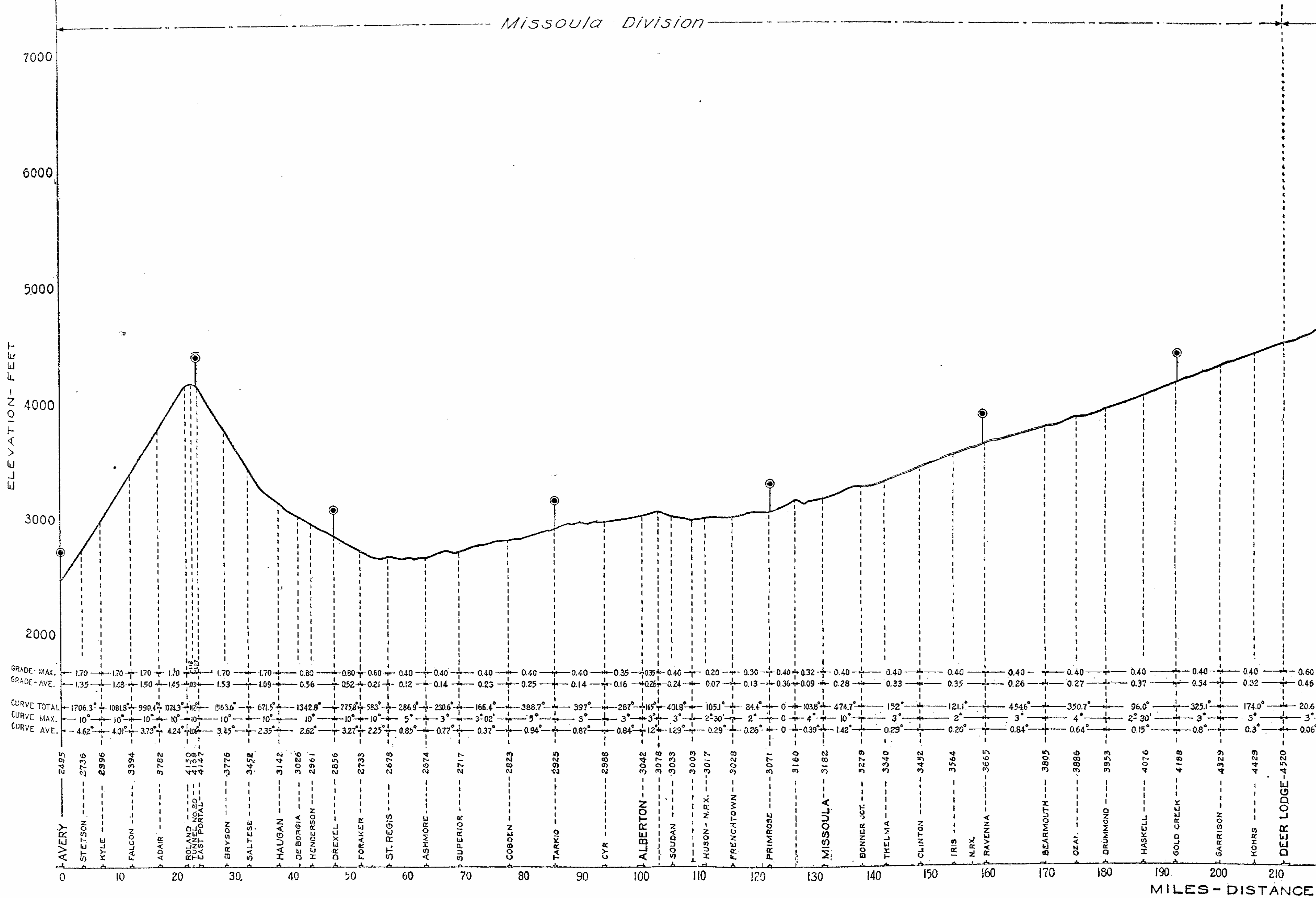
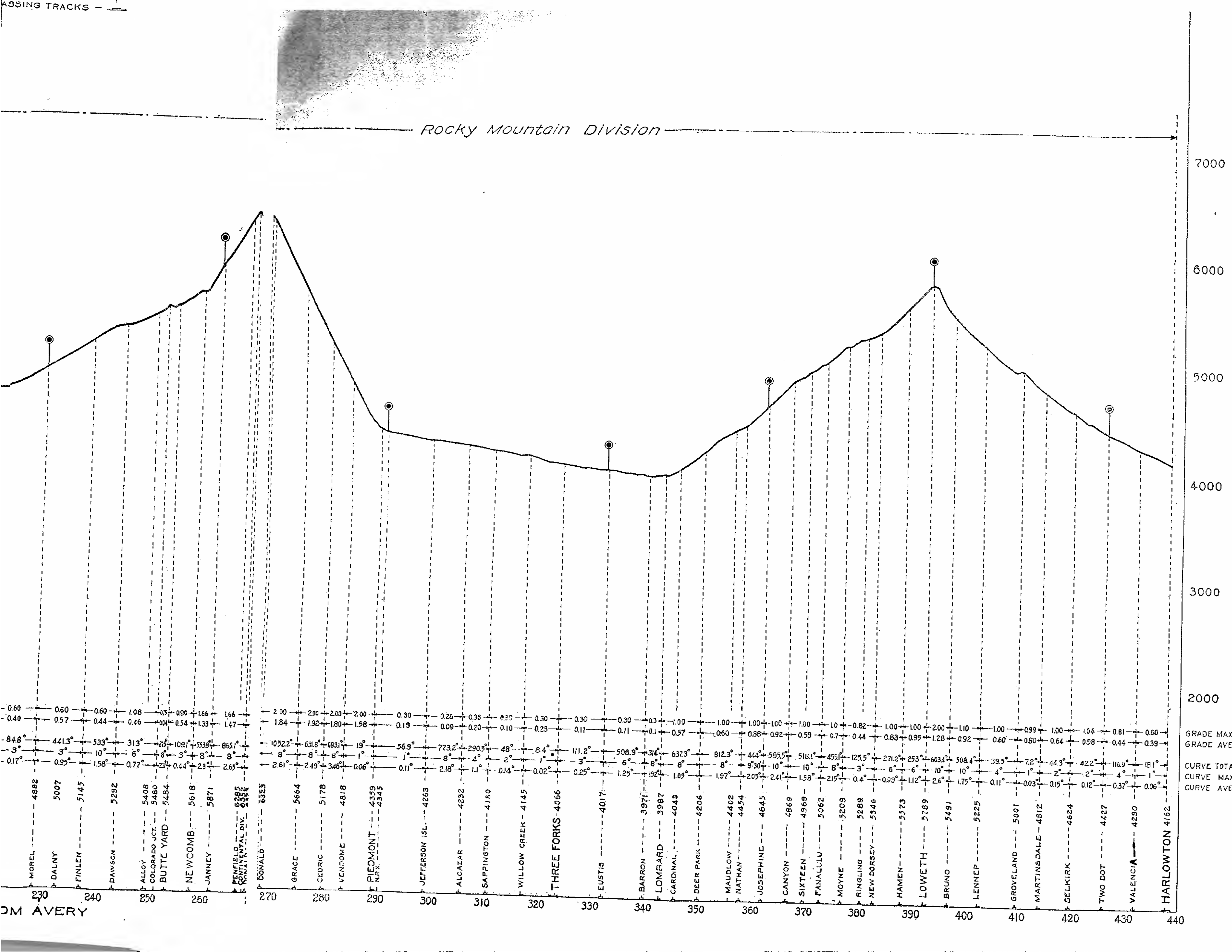


Fig. 1. Transmission Lines of the Montana Power Co. and Substation Layout for the C., M. & St.P. Electrification

CHICAGO MILWAUKEE & ST. PAUL RAILWAY
MISSOULA AND ROCKY MOUNTAIN DIVISIONS





ASSING TRACKS –
Rocky Mountain Division
7000
6000
5000
4000
3000
2000
GRADE MAX
GRADE AVE
CURVE TOTA
CURVE MAX
CURVE AVE
MOREL 4882
DALNY 5007
FINLEN 5145
DAWSON 5292
ALLOY 5408
COLORADO JCT. 5480
BUTTE YARD 5484
NEWCOMB 5618
JANNEY 5871
PENFIELD 6285
CONTINENTAL DIV.
DONALD 6323
GRACE 5664
CEDRIC 5178
VENDOME 4818
PIEDMONT 4359
N.P.X. 4345
JEFFERSON ISL. 4263
ALCAZAR 4232
SAPPINGTON 4180
WILLOW CREEK 4145
THREE FORKS 4066
EUSTIS 4017
BARRON 3971
LOMBARD 3987
CARDINAL 4043
DEER PARK 4206
MAUDLOW 4402
NATHAN 4454
JOSEPHINE 4645
CANYON 4869
SIXTEEN 4969
FANALULU 5062
MOYNE 5209
RINGLING 5289
NEW DORSEY 5346
HAMEN 5573
LOWETH 5789
BRUNO 5491
LENNEP 5225
GROVELAND 5001
MARTINSDALE 4812
SELKIRK 4624
TWO DOT 4427
VALENCIA 4290
HARLOWTON 4162
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
OM AVERY

TABLE I

SUBSTATIONS AND THEIR EQUIPMENT

Substations	Transformers	Motor-Generators
Rocky Mountain Division		
Two Dot	Two 2500 kv-a.	Two 2000 kw.
Loweth	Two 2500 kv-a.	Two 2000 kw.
Josephine	Two 2500 kv-a.	Two 2000 kw.
Eustis	Two 2500 kv-a.	Two 2000 kw.
Piedmont	Three 1900 kv-a.	Three 1500 kw.
Janney	Three 1900 kv-a.	Three 1500 kw.
Morel	Two 2500 kv-a.	Two 2000 kw.
Missoula Division		
Gold Creek	Two 2500 kv-a.	Two 2000 kw.
Ravenna	Two 2500 kv-a.	Two 2500 kw.
Primrose	Two 2500 kv-a.	Two 2000 kw.
Tarkio	Two 2500 kv-a.	Two 2000 kw.
Drexel	Two 2500 kv-a.	Two 2000 kw.
East Portal	Three 2500 kv-a.	Three 2000 kw.
Avery	Three 1900 kv-a.	Three 1500 kw.

volt direct current used for traction purposes. Each motor generator consists of two 1500-volt direct-current generators connected in series and driven by a 2300-volt synchronous motor supplied from the substation high tension busses through a three-phase, 100,000/-2300-volt transformer and is guaranteed for a maximum five-minute overload of 200 per cent. The rated capacities of these stations are given in Table I.

The railway company's high-tension line, arrangement of apparatus in the substations and the general layout of the 3000-volt distribution or trolley system, are shown diagrammatically in Figs. 1 and 3.

The contact wires of the trolley system consist for the main line of two No. 0000 B.&S. grooved trolley wires flexibly supported side by side from a ½-in. steel catenary and tapped at intervals of about every 1000 ft. to a feeder which connects to the adjacent substation busses through switches and automatic circuit breakers. Over passing, industrial and similar tracks only a single No. 0000 copper trolley wire is used. There is an insulated air gap in the trolley in front of each substation separating the trolley system west of the substation from that east of the substation; that is, portions east and west of the substations are fed, respectively, through separate feeder breakers. There is also an insulated air gap at the beginning and end of every passing track, so that by means of a section switch installed in the feeder at the gap the district between any two gaps may be isolated in case of trouble so as to permit operation up to the location of the open switches.

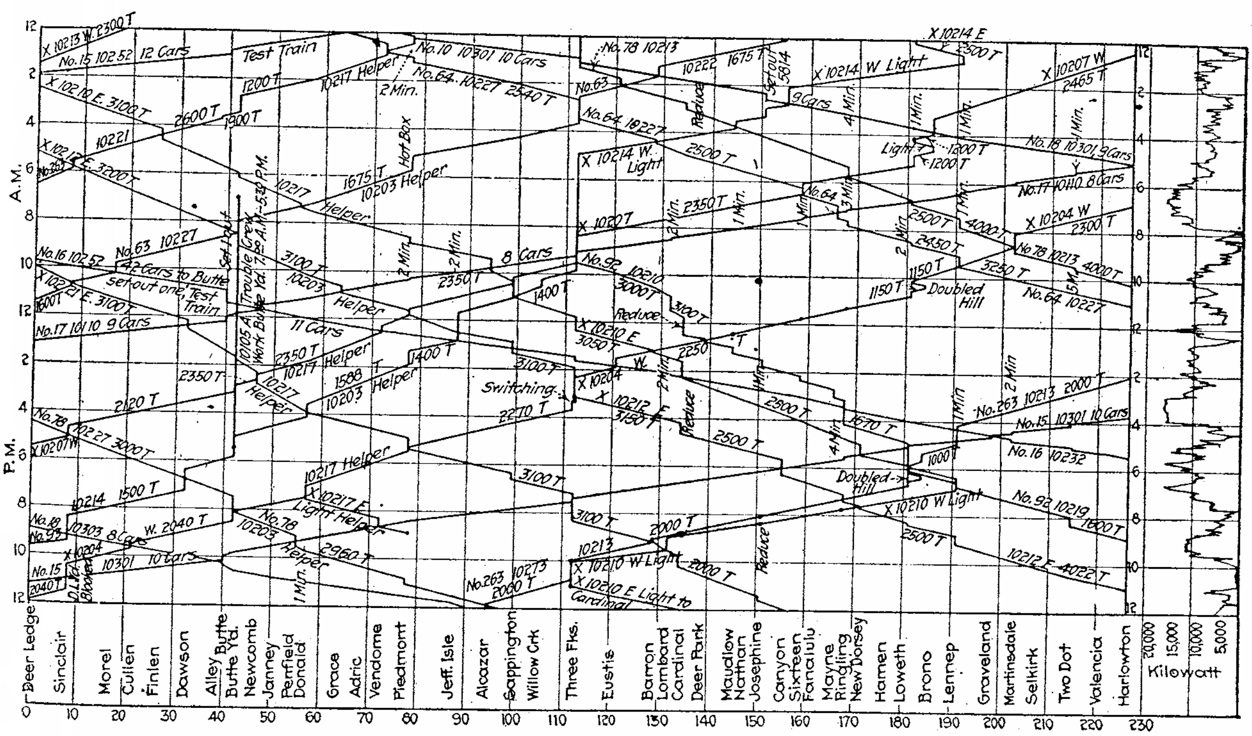
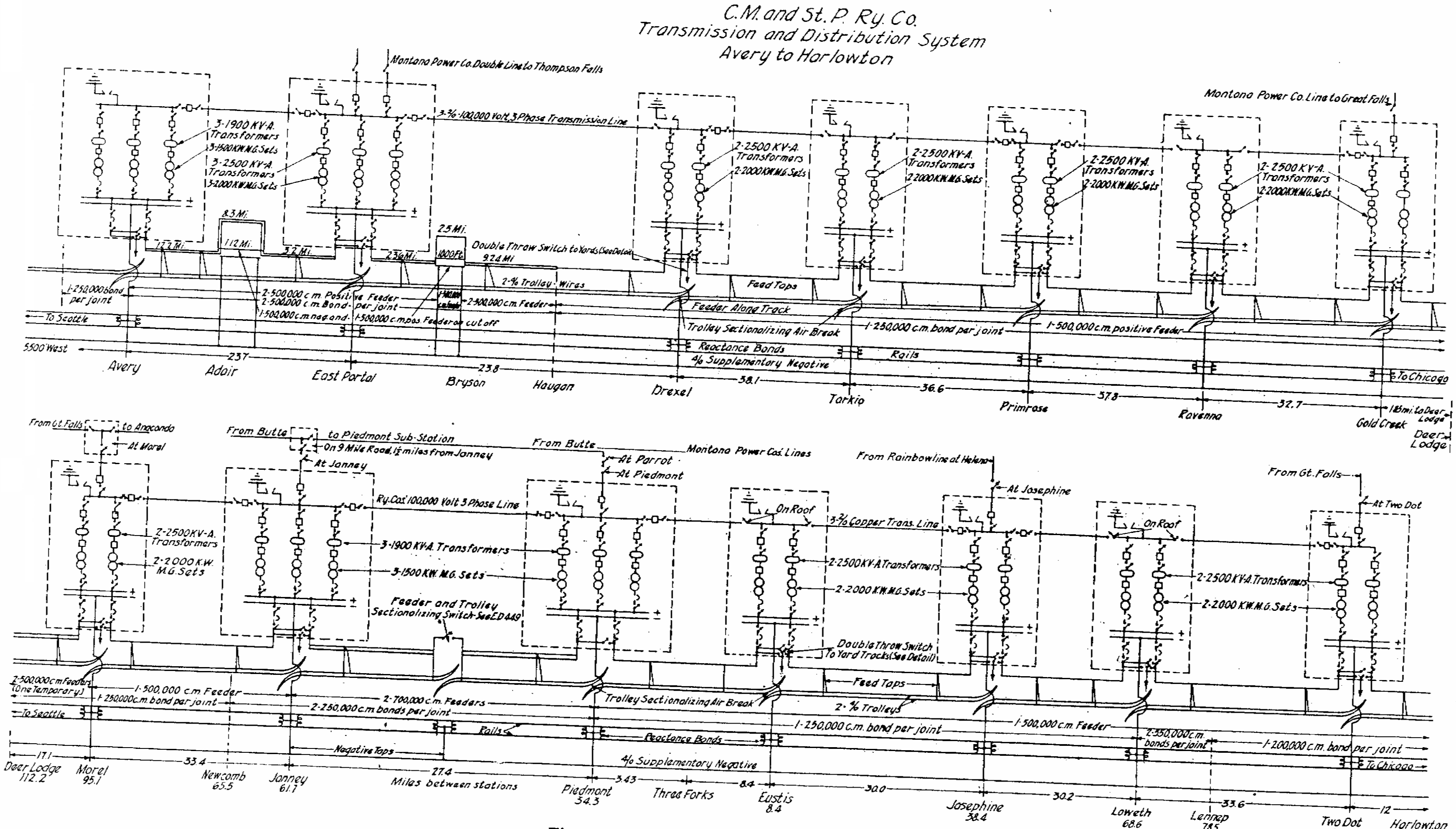


Fig. 2. Graphic Train Sheet and Load Curve for the Rocky Mountain Division, February 19, 1920



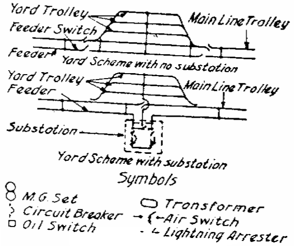


Fig. 3. Diagram of Transmission and Distribution System, Avery to Harlowton

Feeder and trolley sectionalized at all substations and railway stations.
One No. 0000 feeder tap to each trolley every 1000 feet.
Reactance bonds 5000 to 6000 feet apart.
Negative tapped to middle point of every second reactance bond.
Side track rails are bonded in series with the supplementary negative.
One rail bonded with one 250,000 cir. mil bond per joint in yards.
Trolley feed taps are disconnected for a distance of one mile each side of each substation where there is a single feeder and two miles where there is double feeder, except at Ravenna where the tunnel entrance East, and at East Portal where the tunnel entrance West will limit the distance.
Yard switch at substation left open. Yard trolley at substation connected to main line trolley of east end of yards.
Signal: Two No. 4 B.&S. copper wires carried on trolley poles. Fed both directions from substations, 4400 volts a-c.
Power Limiting: Two No. 8 B.&S. copper wires carried on trolley poles—Morel to Two Dot—1200 volts d-c.

The return circuit consists of the 90-lb. running rails and, in general, of a No. 0000 B.&S. copper supplementary negative wire which is run along the trolley poles and connected to the track at intervals averaging about 8000 ft. through each alternate signal system reactance bond. This supplementary negative, however, is intended more as a safety measure to bridge open rail bonds than to increase the return circuit conductivity. However, on various feeder cutoffs on the mountain grades, where the conductivity of the positive circuit closely approaches that of the return circuit, one of the two feeders on the cutoff is in parallel with the running rails and is provided for the purpose of increasing the return circuit conductivity.

Power Demand Controlled by Train Dispatcher

The terms of the power contracts are similar and each provides for a minimum payment on basis of a 60 per cent load factor. Where the load factor exceeds 60 per cent payment is made on basis of the actual kilowatt-hours consumed, the rate being 5.36 mills per kilowatt-hour. The demand is controlled for each division by means of a so-called power indicating and limiting system,* which on the Rocky Mountain division was put into operation early in the year 1918 and on the Missoula division a few months ago. Briefly, this system is so arranged as to indicate and record at the dispatcher's office at Deer Lodge the total kilowatts or demand being supplied in any instant by the power company to the railway company and to prevent the maximum demand from exceeding a certain amount as determined by the "demand setting made by the dispatcher," this limiting action being secured by lowering of the substation direct-current voltage and therefore of the train speeds.

The effect of this limiting action is clearly indicated on the graphic time-table (Fig. 2) of train movements on the Rocky Mountain division for February 19, 1920, and corresponding load curve traced by tapalog meter of the power indicating and limiting system with the load limit set at 16,000 kw.

The percentage of time when the limiting action will take place, for a given amount of business, will depend on the demand setting and on the possibilities of spacing the trains so that as few as possible will at one time be operating on the heavier grades, the latter matter, except as regards passenger trains and certain time freights, being to a considerable extent in the hands of the train dispatchers. The slowing up of the train speeds of course results in increased train and enginemen's expense and increased time in getting freight over the road, and a proper balance must be struck between this increased expense and the saving in power cost and the limit setting determined upon accordingly. Table II gives an idea of the percentage of time the limiting action takes place with average kilowatt load and settings as indicated, this percentage being based on the number of hours the limiting system was actually in service.

TABLE II

ST. PAUL ELECTRIFICATION, LIMIT SETTING AND AVERAGE KILOWATT-HOUR TAKEN MONTHLY

Month	Limit Setting	Average Monthly Load in Kilowatts	Per Cent Time Limiting Action Takes Place
July, 1918	12,000	8020	13.0
Aug., 1918	12,000	7820	15.5
Sept., 1918	12,000	6675	8.2
May, 1919	14,000	7840	4.62
Aug., 1919	14,000	7650	4.12
Sept., 1919	14,000	8230	9.50
Oct., 1919	14,000	8420	10.65
Nov., 1919	14,000	7115	8.24
Feb., 1920	16,000	8625	2.40
Mar., 1920	16,000	8680	2.20
April, 1920	16,000	8620	.90

In arriving at the amounts chargeable for power against the respective classes of train service, the total kilowatt-hours to be paid for—that is, the actual kilowatt-hours, or the actual kilowatt-hours increased, if necessary, to correspond to a minimum 60 per cent load factor—is taken and from it is deducted the kilowatt-hours metered against substation lighting, auxiliary power, signal system supply, etc., amounting to about 1 per cent. The remaining kilowatt-hours is then divided between the different classes of train service, freight, passenger and non-revenue, in proportion to the total net kilowatt-hour readings obtained for these respective services from wattmeters installed in the locomotives. These readings are taken by the engine crew on entering or leaving the engine on the form provided for the purpose, and a record of the power consumption of each train is thus obtained. The readings are referred to as "net" readings, as they represent motored energy less regenerated energy.

*This system was described in the GENERAL ELECTRIC REVIEW for April, 1920, page 292.

TABLE III

ST. PAUL ELECTRIFICATION—AVERAGE INPUT

Month	Rocky Mountain Division			Missoula Division		
	Actual Kw-Hrs. System Input for Locomotives	Net Kw-Hrs. Input at Locomotive	Ratio	Actual Kw-Hrs. System Input for Locomotives	Net Kw-Hrs. Input at Locomotives	Ratio
January	6,381,233	4,838,480	75.9	5,540,581	3,753,430	67.6
February	4,610,607	2,921,840	63.3	4,107,960	2,702,710	65.8
March	5,795,859	4,351,126	75.2	5,412,048	3,469,120	64.2
April	5,949,840	3,962,650	66.6	5,429,932	3,574,080	65.8
May	5,803,455	4,146,517	71.4	5,745,397	3,795,770	66.2
June	5,662,650	4,100,810	72.3	5,697,785	3,853,590	67.6
July	5,744,738	3,794,940	66.2	5,318,692	3,505,630	65.8
August	5,648,815	3,755,280	66.5	5,133,008	3,255,820	63.4
September	5,892,430	3,799,830	64.5	5,102,562	3,434,010	67.3
October	6,222,486	3,971,149	63.8	5,389,883	3,654,955	67.8
November	5,095,937	3,425,458	67.2	4,879,130	3,181,456	65.2
December	5,809,976	3,830,870	65.8	4,971,601	3,382,700	67.9
Total	68,618,026	46,898,850	68.3	62,728,579	41,563,271	66.3

The ratio of the total net locomotive wattmeter readings, all services, to the total actual kilowatt-hours input to the system chargeable to locomotives for the various months of 1919 is given in Table III.

As there are no wattmeters installed in the direct-current side of the substations, a ratio for net substation output to system input or to locomotive is not obtainable. There are, however, wattmeters in the circuits of the individual motor-generator sets and Table IV considered in connection with the profile of the line will be of interest in showing the manner in which the energy is distributed among the respective substations, average kilowatts being used for convenience instead of total kilowatt-hours, and the whole of the year 1919 being taken.

Operating Figures for 1919

The figures in Table V show for the year 1919 the net kilowatt-hours per thousand gross ton-miles for freight revenue service and passenger service, respectively, and corresponding cost of these kilowatt-hours at the high tension bus or point of delivery of the power to the railway system. The lesser consumption of energy during the summer months as compared with the winter months will be noted. The figures for the passenger service are approximate, as the ton-mile data are based on the assumption of an average weight per car, no record of the particular cars handled in all the separate trains being available.

The cost of maintaining and operating the transmission lines, substations and trolley system for the year 1919 is given in Table VI

TABLE IV

ST. PAUL ELECTRIFICATION—AVERAGE INPUT OF SUBSTATIONS

Rocky Mountain Division

Substation	Average Annual Kw. Input Net to Motor Generators	
	* Total	** Per Motor-Generator
Two Dot	895	813
Loweth	962	783
Josephine	1014	1013
Eustis	1022	1016
Piedmont	1218	617
Janney	1390	559
Morel	1047	1072
System Total	7548	....

Missoula Division

Substation	Average Annual Kw. Input Net to Motor Generators	
	* Total	** Per Motor-Generator
Gold Creek	1150	1128
Ravenna	915	1115
Primrose	908	925
Tarkio	843	803
Drexel	790	778
East Portal	1390	778
Avery	812	523
System Total	6808	....

* Total kw-hrs. computed on the basis of 8856 hours in the year (four extra days in December being included).
** Computed from total kw-hrs. and total running hours of motor generators.

TABLE V

ST. PAUL ELECTRIFICATION—OPERATING STATISTICS FOR 1919

Net Kw-Hrs. per Thousand Gross Ton-Miles

Month	Thousand Gross Ton-Miles, Trailing	Trailing		Train		Load Factor	Cost of Kw-Hrs. per M. Trailing, Gross Ton-Miles, Cents
		At High Tension Bus	At Locomotive	At High Tension Bus	At Locomotive		
Rocky Mountain Division							
Freight Service:							
January	98,478	47.8	36.3	41.2	31.3	63.7	25.7
February	79,859	43.1	27.3	37.3	23.6	57.7	24.0
March	118,297	39.0	29.3	33.9	25.5	65.3	20.9
April	121,646	38.5	25.6	33.1	22.0	61.1	20.7
May	124,395	36.5	26.1	31.7	22.6	56.0	20.9
June	122,264	36.7	26.2	31.7	22.9	56.4	20.9
July	120,723	36.7	24.3	31.6	20.9	55.4	21.3
August	111,092	40.9	27.2	34.9	23.2	54.6	22.4
September	115,787	39.7	25.6	34.1	22.0	58.8	21.7
October	108,920	45.8	29.2	39.4	25.1	60.0	23.6
November	86,267	44.0	29.6	37.7	25.3	50.9	27.8
January-November	Averages	40.5	27.7	34.8	23.8	57.3	22.5
Rocky Mountain and Missoula Division							
January	87,958	44.3	29.9	38.6	26.1	....	23.8
February	73,481	39.8	26.2	35.2	23.2	....	21.7
March	103,613	40.3	25.8	35.6	22.8	....	21.6
April	109,133	38.5	25.4	34.1	22.4	....	20.2
May	118,331	37.9	25.1	33.5	22.2	....	20.3
June	116,660	37.8	25.6	33.3	22.5	....	20.3
July	106,045	38.1	25.0	33.5	22.0	....	20.4
August	101,017	38.8	24.6	34.3	21.8	....	20.8
September	99,578	38.5	25.9	34.1	22.9	....	20.6
October	100,504	40.0	27.1	35.3	23.9	....	21.4
November	78,459	45.3	29.5	39.2	25.5	....	24.3
January-November	Averages	39.7	26.3	35.0	23.1	....	21.3
Rocky Mountain and Missoula Divisions Combined							
January-November	2,302,507	40.1	27.1	34.9	23.5	....	21.9
January-December	2,476,085	....	....	....	....	....	22.3
Passenger Service:							
January-November	340,480	56.8	38.7	39.7	27.1	....	38.4
January-December	378,080	....	....	....	....	....	38.1

TABLE VI

ST. PAUL ELECTRIFICATION—DISTRIBUTION OF OPERATING COSTS FOR 1919

Account		Total All Services	Per Unit
255.	Power substation buildings	$ 8,487	$ 606.00 per building
257.	Power transmission system	1,773	4.87 per mile
259.	Power distribution system	78,461	179.00 per route-mile
261.	Power line poles and fixtures	24,299	55.50 per route-mile
306.	Power substation apparatus	40,224	2,870.00 per station
383. } 395. }	Train and yard power produced	102,152	7,300.00 per station
	Total	$255,396	

TABLE VII

UNIT COSTS, INCLUDING COST OF POWER

1.	Cost per thousand gross ton-miles trailing freight as actually distributed in accounts........	28.8 cents
2.	Cost per thousand gross ton-miles train freight as actually distributed in accounts..........	24.9 cents
3.	Cost per thousand gross ton-miles trailing freight on basis distribution in proportion to freight kilowatt-hours..	30.2 cents
4.	Cost per thousand gross ton-miles train freight on basis distribution in proportion to freight kilowatt-hours..	26.2 cents
5.	Cost per actual kilowatt-hours, delivered to locomotives	1.1 cents

* NOTE.—The items in the table refer to the classification numbers prescribed by the Interstate Commerce Commission for steam railroad accounting. The several groupings are defined as follows:

255. Power Substation Buildings.
This shall include the cost of repairing buildings of power substation * * * used to transform power for the operation of trains and cars, and to furnish power, heat, and light for general purposes: * * *

257. Power Transmission System.
This account shall include the cost of repairing systems for transmitting high-tension power from power houses to the point where transformed for use, including the cost of work-train service and special tools furnished for such work.

259. Power Distribution Systems.
This account shall include the cost of repairing electric distribution systems, whether overhead, surface, or underground, for conveying low-tension power for propelling trains and cars, and for power, heat, light, and general purposes.

261. Power Line Poles and Fixtures.
This account shall include the cost of repairing and replacing electric line poles, cross arms, and insulating pins; brackets and other pole fixtures; and braces and other supports for holding poles in position; also the cost of repairing structures primarily for supporting the overhead electric construction.

306. Power Substation Apparatus.
This account shall include the cost of repairing machinery and other apparatus, including special foundations, for transforming or storing power in power substations used for the operation of trains and cars and for power heat, and light for general purposes.
Details of Power Substation Apparatus.

Rotary Converters	Switchboards
Storage Batteries	Transformers

383. Yard Switching Power Produced.
This account shall include the cost of the production and distribution of electric power used in operating locomotives and cars in switching service in yards where regular switching service is maintained, and in terminal switching and transfer service.
EMPLOYEES.—The pay of employees engaged in operating electric-power stations and substations, such as engineers, firemen, electricians, dynamo men, oilers, cleaners, and coal passers.
FUEL.—The cost of coal, oil, gas and other fuel, including the cost of labor unloading or stocking fuel.
WATER.—The cost of water used to produce steam or to operate water plants, including pumping, rent of ponds, streams, and pipe lines, also water tests, boiler compounds, and other like supplies and expenses.
OTHER SUPPLIES AND EXPENSES.—The cost of lubricants, such as oil and grease used in lubricating engines, shafting, dynamos, and pumps; cost of waste, carbon brushes, fuses, lamps, and other supplies; also the cost of heating and lighting power plants, and other expenses not elsewhere specified in connection with operation of electric-power plants.

395. Train Power Produced.
This account shall include the cost of producing and distributing electric power for the propulsion of electric locomotives and cars in transportation train service. Otherwise same as account No. 383.

and a final figure thus arrived at showing the approximate total operating costs involved in the delivery of the electric energy to the locomotives is given in Table VII.

Conclusion

The installation being comparatively new it might naturally be assumed without consideration of other facts that the figures for the maintenance are considerably lower than those which will eventually obtain, but it should also be borne in mind that the maintenance and operating costs given will, except for power, remain more or less constant so far as any consideration of their being affected by the business handled is concerned, so that the cost per thousand ton-miles would be correspondingly reduced as business is increased. It is also expected that considerable improvement will be effected in maintenance methods, which would again tend to reduce costs. The figures are therefore given merely to show the results which are at present being obtained.