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POWER-LIMITING AND INDICATING SYSTEM OF THE C., M. & ST. P. RWY.

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Power-limiting and Indicating System of the C., M. & St. P. Rwy.

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THE Power Limiting and Indicating System constitutes one of the many new and novel features developed and installed as part of the original equipment furnished by the General Electric Company to the Chicago, Milwaukee and St. Paul Railway for the electrification of its Rocky Mountain and Missoula Divisions. This system has overcome so many difficult problems and performs so satisfactorily it is believed a detailed description will be of interest.

Several different schemes were proposed and investigated, such as increasing the frequency of the circuit proportional to the power input, adding electrical impulses of different kinds, etc., but the system which was finally adopted and which will be described was found to be the simplest, to require the least number of pilot wires, and to necessitate very little apparatus in either the substations or the dispatcher's office.

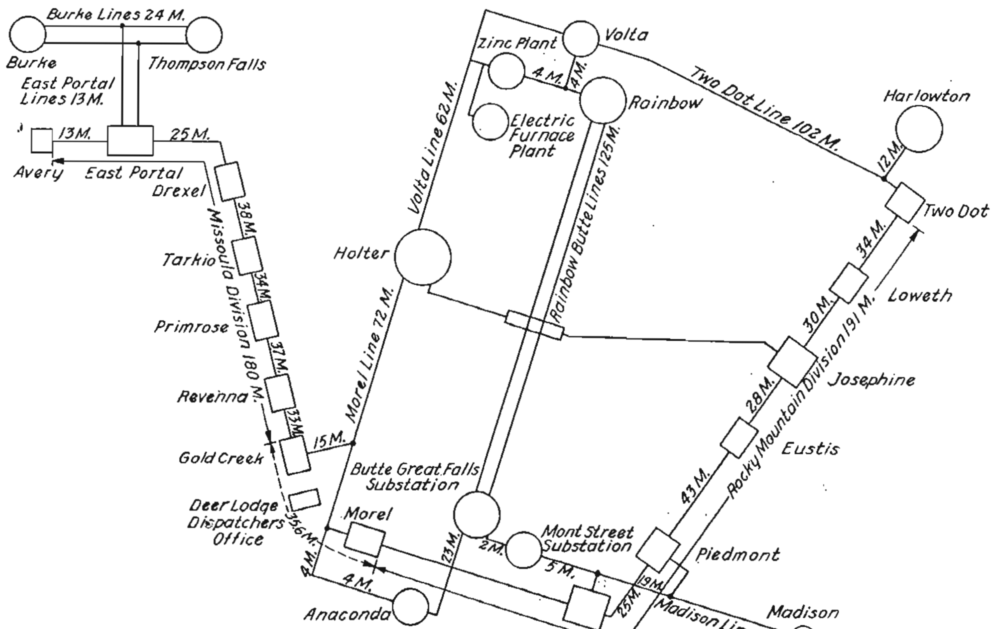

Fig. 1. General Connections of the 100,000-volt System of the Montana Power Company and Transmission Line of the Chicago, Milwaukee & St. Paul Railway, Including Location of the 3,000-volt d-c. Railway Substations

The general requirements specified by the railway were based on its desire to obtain an equipment which, with heavy trains comparatively few in number, would give the highest load-factor consistent with good railroading; and on the part of the Montana Power Company to prevent excessive peaks which might cause serious voltage variations and require the installation of excess generating apparatus to take care of the railway load. The power company was also very desirous of obtaining means by which the total power supplied to the railroad transmission line at a number of different points, over a distance of 220 miles, could be accurately recorded at one place and on one meter; to replace the former practice of having laboriously to add up records of as many as five curve-drawing meters, which are somewhat difficult to synchronize as to time, in order to obtain proper peak load data upon which to base the price of power. It is, therefore, very evident that the accomplishment of these results is of great mutual advantage and benefit to the railway company and the power company.

The 220-mile Rocky Mountain Division was selected for the first installation as being the most difficult section due to the five feeding points and the heavy grades with regenerative braking. The apparatus described was designed, built, installed, and tried out in service on this section before going ahead with similar equipment for the 220-mile Missoula Division which has only two feeding points.

The equipment for the Rocky Mountain Division as first installed was based on metering the power at the five feeding points (Two Dot, Josephine, Piedmont, Janney, and Morel Substations), but was later changed to meter the power at the low-tension side of the motor-generator set step-down transformers. This change was decided upon by the two companies concerned as it was found impossible to prevent the transfer of very large blocks of power from one of the power company's lines to the other lines through the railway company's transmission line at times of switching or line troubles with resultant losses not correctly chargeable to the railway company, added duty to the metering equipment due to the necessity of adding and then subtracting this power, excess meter capacity, etc. The Missoula Division with only two feeding points did not have these objections and power for this division is metered on the high-tension side.

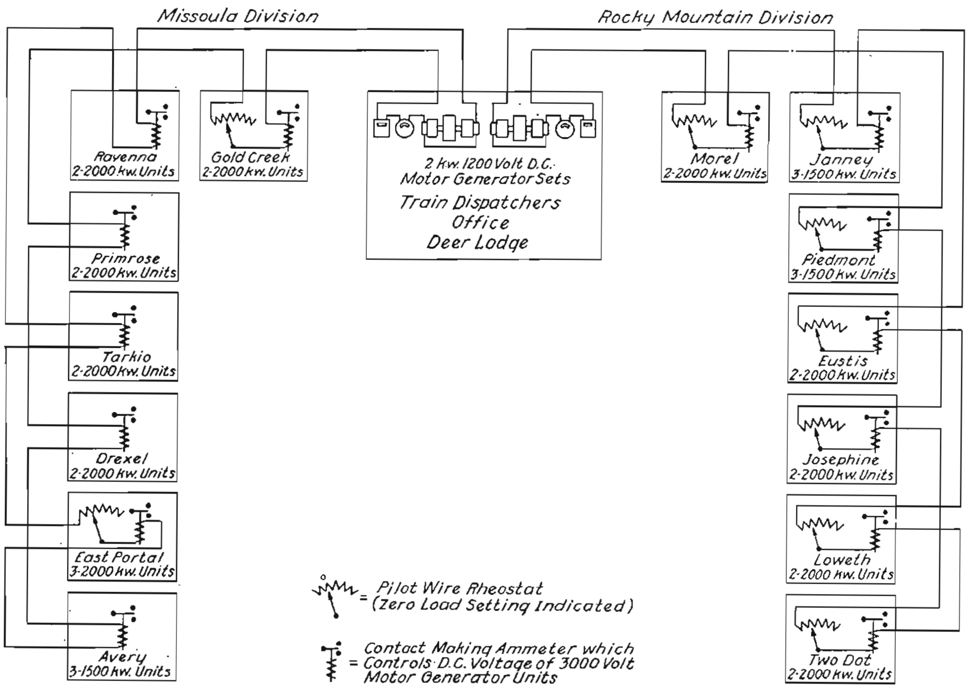

Fig. 2. Diagram Showing General Connections of the Pilot Wire Circuit and Location of the Contact-making Wattmeters for the Rocky Mountain & Missoula Divisions

The main features of the power company's transmission line, railway company's transmission line, feeding points, location of substations and train dispatcher's office is shown in Fig. 1. The dispatcher's office is located at Deer Lodge, Mont., the center of the 440-mile electrification, and all the indicating and recording apparatus for both divisions is installed at this point.

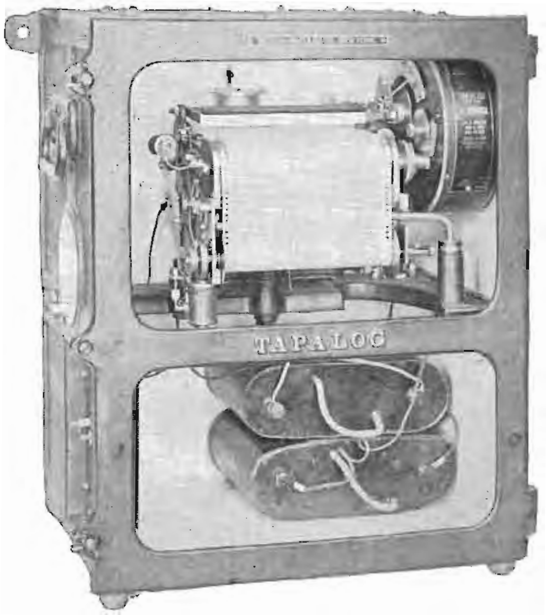

Fig. 3. Curve Drawing Kilowatt Totalizing Wattmeter. Dispatcher's Office

The complete system comprises the two separate and distinct functions of limiting the maximum power demand at the will of the train dispatcher and of indicating and recording the total net power at all times. The combination of these two functions accomplishes the following remarkable results:

(1) Independent of the number of feeding points, it indicates to the train dispatcher at all times the total net amount of energy being delivered to his division and it makes a permanent record for future study and as a basis for power bills.

(2) It automatically deducts regenerated power if returned to the power company's lines or transfer of power from one line to another over the railway company's transmission line.

(3) It automatically limits the amount of power supplied to the division by lowering the trolley voltage and slowing down the trains so that the peak load on the system cannot exceed a certain predetermined maximum.

(4) Its maximum limit can be changed instantly, easily, accurately, and directly by the dispatcher at any time without any necessity of notifying substation operators.

(5) It is capable of reducing the peak power demand by 30 per cent.

(6) If desired, the equipment can be adjusted so that the lightly loaded substations will not be affected, thereby providing the highest possible voltage for the operation of passenger trains.

(7) If desired, the equipment can be adjusted to reduce the voltage on the heaviest loaded substations at the time of peak demand (above the maximum limit) slightly in advance of the other stations, thereby tending to equalize the load on all the stations.

(8) If an excessive demand for power occurs near any one substation, the voltage of the nearest substation is automatically lowered without affecting the voltage of the other substations, dividing the load between this substation and the stations on either side.

Fig. 4. Indicating Kilowatt Totalizer. Dispatcher's Office

(9) The total power fed in at any point or transferred from one power line to another or the amount returned due to regeneration can be easily taken care of by a change in the ratio of the current transformers, or by an adjustment of the wattmeter rheostats.

Preliminary negotiations between the railway company, the power company, and the manufacturer were completed in November, 1915; the equipment was completed and installed for the first division in 1917, and has been in successful operation since that time. The equipment for the second or Missoula Division has been installed and is now in operation.

The system is essentially an ohm-meter on a large scale; consisting of a pilot wire circuit extending the length of the division, connecting in series all of the substations, and the train dispatcher's office with contact-making wattmeters and suitable rheostats at the incoming power points, and contact-making ammeters with voltage lowering generator rheostats in each substation.

As each of the divisions was about 220 miles in length, No. 8 B & S. copper wire was selected as being the smallest wire that for mechanical reasons should be used. To give the utmost reliability, a two-wire pilot circuit was installed in each instance. This pilot wire is placed on the trolley poles beneath the 3000-volt direct-current feeders, Fig. 18. It is very probable that one wire with a good ground return would be satisfactory, but as this was the first installation it was thought best not to take any risk of such an arrangement being unsatisfactory and therefore a complete non-grounded metallic circuit was installed. The insulators were selected after a very extensive investigation of the comparative merits of porcelain and glass, leakage constants, etc., a special attempt being made to obtain an insulator which would give a minimum surface leakage under all atmospheric conditions. A 6600-volt porcelain insulator was chosen. The leakage under the most severe conditions has been so slight that the accuracy and operation has not been affected. No. 4 B & S. wire is used at all crossings.

A constant source of direct-current potential is applied across the two ends of the pilot wire loop at the dispatcher's office, power being obtained from a 2-kw. 1200-volt direct-current motor-generator set, the voltage of which is held constant by a standard voltage regulator. The voltage applied to the pilot wire is determined by the length of the division, the resistance of the pilot wire, the number of substations, and the power feeding points. The equipment as finally worked out only requires a maximum of 1200 volts direct current for the 220-mile division, or 440 miles of pilot wire.

The indicating and limiting feature is obtained by inserting or removing a certain number of ohms or resistance for a definite change in the kilowatt demand which causes a definite decrease or increase in the current flowing in the circuit when a constant voltage is held across the pilot wire.

The contact-making wattmeter resistances and the pilot wire contact-making ammeters are connected in series with the pilot wire as shown in Fig. 2, which shows connections for both divisions. As the Rocky Mountain Division has the greatest number of feeding points, and maximum regeneration, the equipment of this division will be described in detail.

Due to the necessity of accounting for the regenerated power from the locomotives, or the transfer of power through the 100,000-volt 60-cycle three-phase transmission line of the railway company, it was necessary to provide a so-called Zero Center Meter, which made necessary having either the resistance for the total power or the regenerated and transferred power always in circuit at the no-load position. The total amount of power in both directions, for which it was necessary to provide resistance, is shown in Table I. It will be seen that it would have been necessary to provide resistance for a total power input of 70,000 kw. and 21,000 kw. for regeneration. In order to obtain greater accuracy it was therefore decided to insert resistance for increase of power and to have

TABLE I

MAXIMUM KILOWATT CAPACITY FOR INCOMING POWER AND REGENERATION AT EACH SUBSTATION

Substations	Maximum Incoming Power in Kw.	Maximum Regeneration in Kw.
Morel	10,000	1,000
Janney	10,000	6,000
Piedmont	10,000	6,000
Eustis	10,000	1,000
Josephine	10,000	3,000
Loweth	10,000	3,000
Two Dot	10,000	1,000

Fig. 5. 2-kw., 1200-volt Motor-generator Set. Dispatcher's Office

the contact-making ammeters arranged to make contact at minimum instead of at maximum current.

This arrangement makes it necessary to have only the resistance for regeneration in the line permanently, while the resistance for power input has to be available only at each wattmeter. This arrangement gives a much smaller total meter scale with greater accuracy at the loads usually obtained.

Harlowton is approximately 434 miles, with a total resistance at 75 deg. F. of approximately 1450 ohms.

After careful consideration of all the different factors, the equipment was designed on the basis of 15 kw. for each ohm resistance and 125 kw. for each step on the wattmeter rheostats, giving a resistance per step of 8⅓ ohms. The kilowatt settings, pilot wire voltage, current in the pilot wire, and resistance are given in Table II, from which it is noted that there are 0.237 amp. flowing in the pilot wire at the peak kilowatt setting.

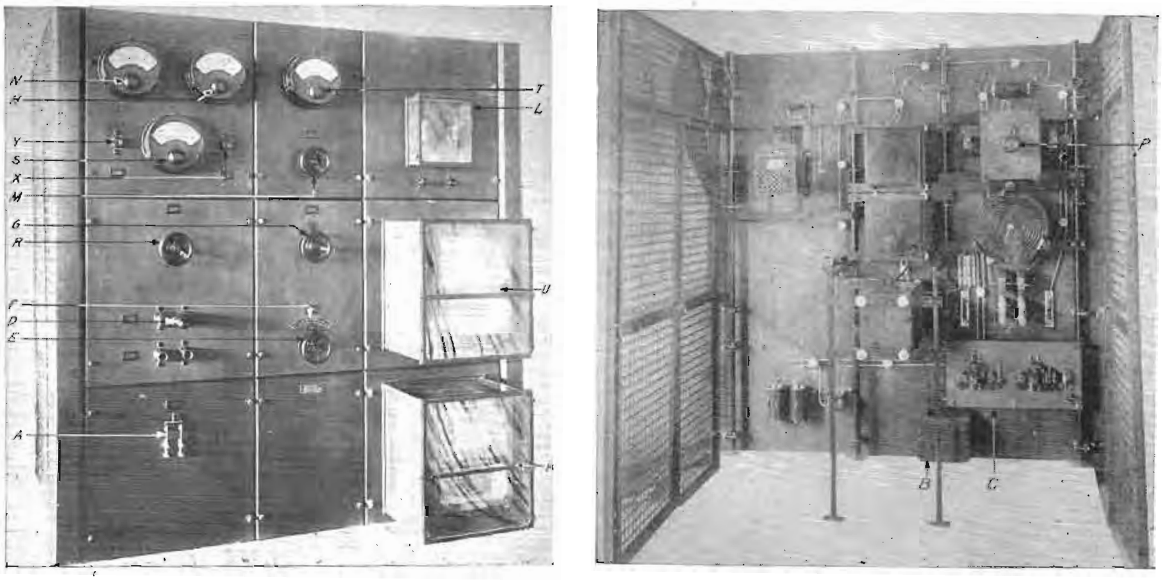

Fig. 6. Switchboard. Dispatcher's Office

A, induction motor switch; **B,** motor starting resistance; **C,** induction motor control panel for 2-kw. pilot wire set; **D,** plus switch for pilot wire connections; **E,** hand wheel of kilowatt limit adjusting rheostat; **F,** kilowatt limit scale marked from 10,000 to 25,000-kw. as noted in Fig. 4; **G,** hand wheel of rheostat for fine adjustment of regulator voltage; **H,** pilot wire indicating voltmeter; **K,** curve drawing voltmeter; **L,** pilot wire voltage regulator; **M,** rheostat for calibrating pilot wire for change in resistance (due to temperature); **N,** pilot wire ammeter; **P,** resistance used when testing out pilot wire for grounds; **R,** rheostat for hand adjustment of pilot wire voltage when regulator is not in use; **S,** milliammeter used to test for leakage; **T,** indicating kilowatt totalizer; **U,** curve drawing kilowatt totalizer; **X,** plug to short circuit ammeter when testing for possible grounds; **Y,** plug to connect the milliammeter between middle point of the two generators and ground.

The total length of the No. 8 B & S. pilot wire loop from the dispatcher's office at Deer Lodge to the farthest substation near

The contact making ammeters are designed to make contact at this current. The apparatus is designed to hold certain definite peak limits in 2000 kw. steps from 10,000 to 25,000 kw. as indicated.

The power-indicating apparatus, with exception of the contact-making wattmeters in each substation, is all installed in the dispatcher's office. The equipment in the dispatcher's office consists of a 2-kw. motor-generator set, a milli-ammeter calibrated in kilowatts, a curve-drawing ammeter also calibrated in kilowatts, a curve-drawing voltmeter to give a permanent record of the pilot wire voltage, and suitable indicating instruments and switchboard to control the motor-generator set.

On account of the very small amount of power available for the operation of the curve-drawing totalizing wattmeter, a special meter had to be developed and both the wattmeter and voltmeters are based on the well-known Tapalog principle. These meters were built by the Wilson Maeulen Company. New York, and one is shown in Fig. 3. The curve-drawing voltmeter and wattmeter are exactly alike with exception of the meter element.

The meter element is a standard Weston direct-current ammeter for the wattmeter, and a standard Weston voltmeter for the voltmeter. A tapping bar actuated by clockwork and dry batteries, in connection with an ink ribbon and paper roll, taps the meter needle at intervals of 5 seconds making a small dot on the paper at the point where the needle happens to be at that time. The totalizing wattmeter and the indicating wattmeter work between limits of 0.190 and 0.353 amp., calibrated for the correct kilowatts. The doors of the meter cases are equipped with switches so that voltage is removed when the door is open. These meters produce a very satisfactory record and have given very successful operation.

Due to the reasons explained, the indicating wattmeter reads a maximum at the lowest amperes and is therefore off scale above 25,000 kw. or when no current is flowing.

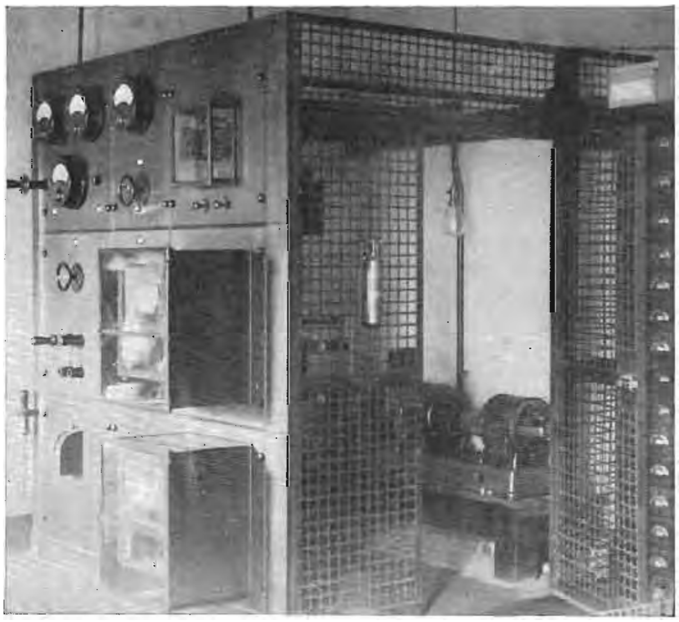

Fig. 7. Photograph of Complete Installation in the Dispatcher's Office, Deer Lodge, Mont.

The motor-generator set consists of two 1-kw. 600-volt generators connected in series for a maximum of 1200 volts direct connected to a 3-h.p. 1800-r.p.m. 110-volt 60-cycle induction motor with ⅓-kw. 125-volt exciter, Fig. 5. Power is supplied by a 3-kw. 2300/110-volt transformer. Separate excitation at 125 volts is used with a standard regulator to obtain very close regulation. The automatic control of this regulator is somewhat special as the voltage variation covers a range from 964 to 1200 volts and must be changed at the same time as the connections of the wattmeters.

The front and back views of the switchboard with notations giving the function of most of the devices are shown in Fig. 6. The general connections are shown in Fig. 8. A view of the complete switchboard as installed in the dispatcher's office is shown in Fig. 7.

Due to the simplicity of the indicating wattmeters, two of these meters have been installed for each division, one on the switchboard and the other in front of the trick train dispatcher as shown in Fig. 9. With this arrangement the dispatcher can tell at a glance the exact amount of power being taken by his division at any instant and also can watch the power demand resulting from his orders to the train crews in charge of trains ascending or descending the mountain grades.

Variation in resistance of the pilot wire due to change in temperature is taken care of in the dispatcher's office by a rheostat which can be easily inserted and the total resistance adjusted to 2000 ohms, the approximate resistance of the pilot wire loop and the coils of the contact-making ammeters, by holding 1200-volts and adjusting the rheostat for 0.6 amp.

The adjustable wattmeter resistances in the substations are automatically short circuited during this operation by reversing the current through the pilot wire, which action short circuits the resistance by means of a polarized relay near the top of the contact-making wattmeter unit, Fig. 11.

The equipment for each substation at which power is supplied is exactly the same on the Missoula Division, only the wattmeters being omitted from the other substations; while the equipment for the seven substations on the Rocky Mountain Division is identical.

The contact-making wattmeter equipment consists of a contact-making wattmeter built along standard meter lines, Fig. 13, with an indicating pointer equipped with contacts moving between the two stationary contacts. The spiral spring of the pointer is connected to the shaft of the pilot wire rheostat located immediately above the wattmeter. This shaft is driven by the motor-driven clutch mechanisms at the top of the supporting framework, as shown in Fig. 11. When contact is made on one side,

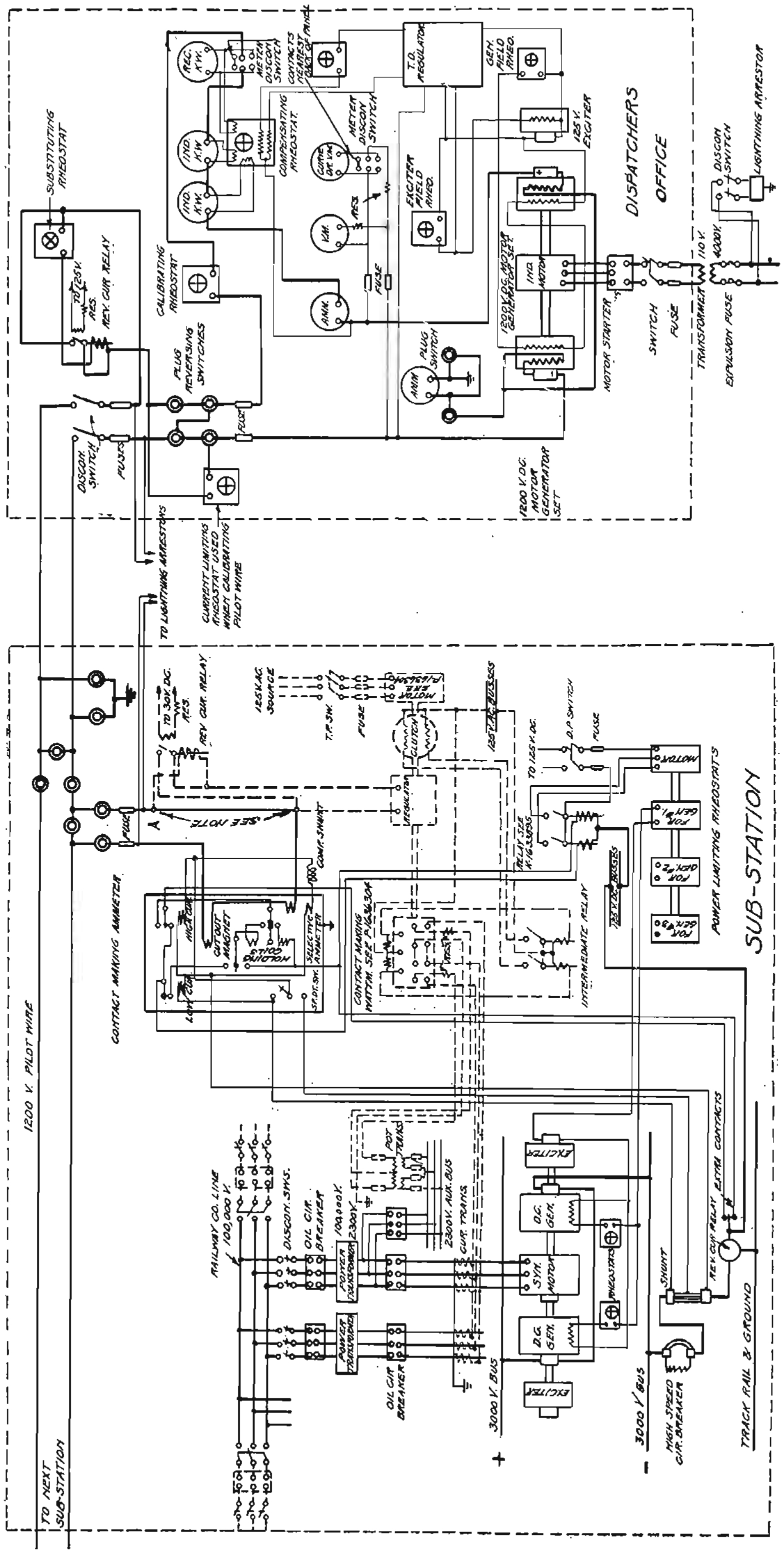

Fig. 8. General Wiring Connections Dispatcher's Office, and Typical Substation

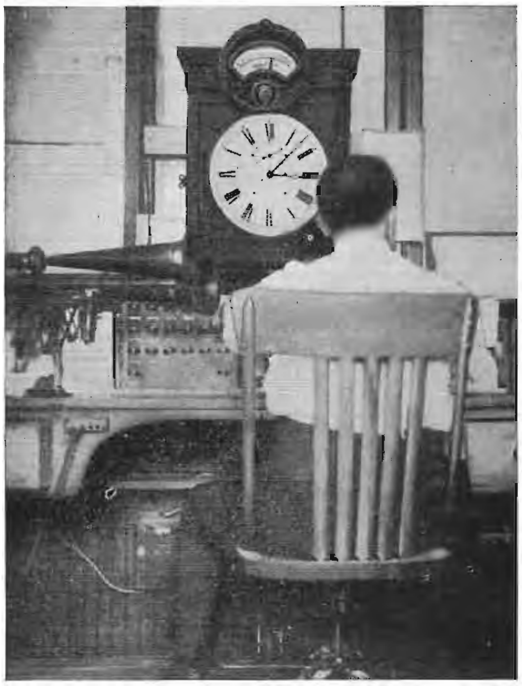

Fig. 9. Photograph Showing Indicating Kilowatt Totalizer in the Trick Dispatcher's Office

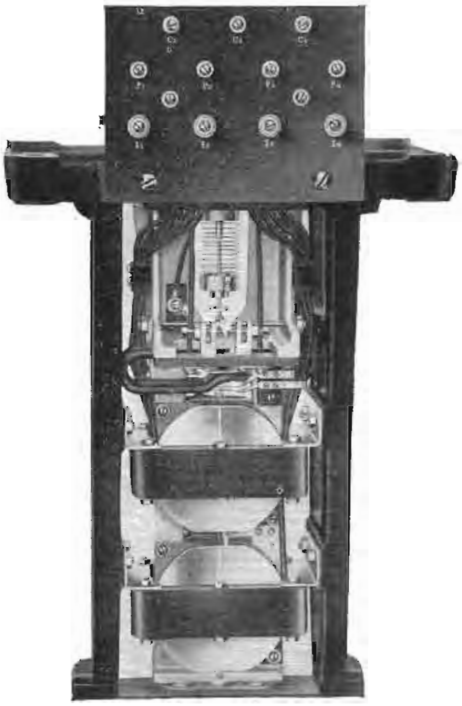

Fig. 10. Contact Making Wattmeter Forming Part of Complete Unit Shown in Fig. 11

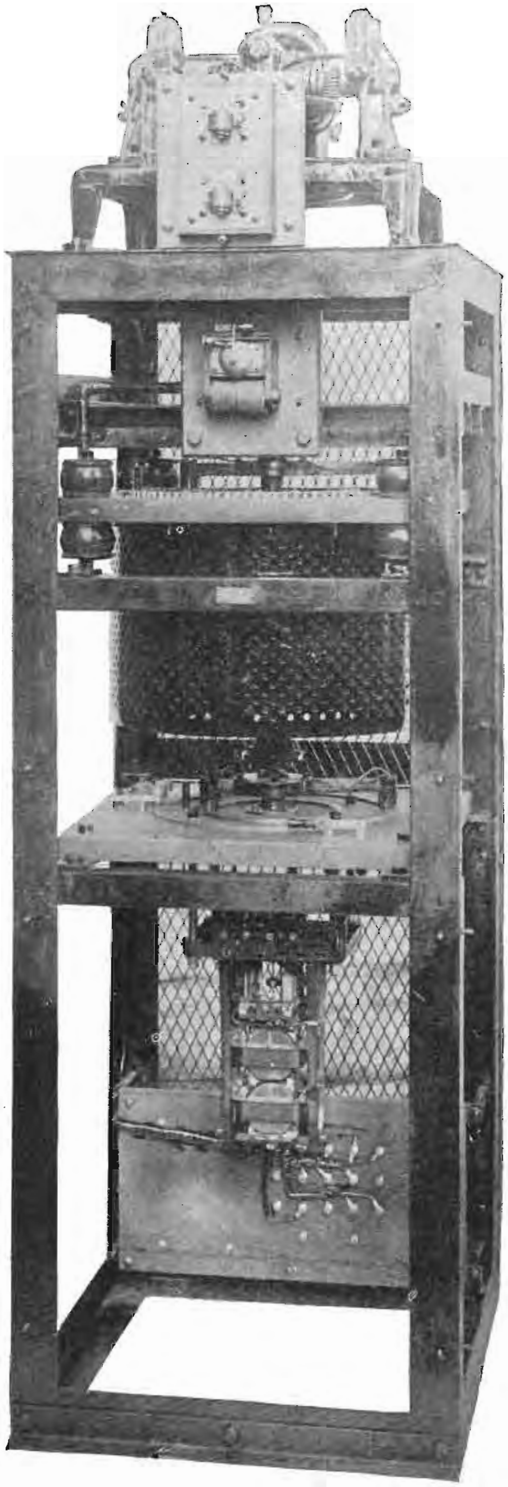

Fig. 11. Complete Motor Operated Clutch Driven Contact Making Wattmeter with Covers Removed

due to an increase in incoming power, the circuit is completed through the clutch coils causing the clutch to engage the rheostat gearing and insert a certain amount of resistance in the pilot wire. At the same time the wattmeter spring is wound up due to the movement of the shaft. This action continues until the torque of the wattmeter is offset by the torque of the spring when a balance is obtained and the clutch circuit interrupted thereby causing the rheostat to come to a standstill. This operation is continued for any increase or decrease in the incoming power.

The rheostats forming part of this unit have the same number of buttons with 8⅓ ohms between each button, a sufficient number of buttons being used to take care of the power requirements as specified in Table I.

The complete motor operated clutch contact-making wattmeter resistance unit is shown in Fig. 11 with the protecting covers removed, while Fig. 12 shows one of the meters installed in the Janney Substation. The generator field rheostats which are used to lower the substation voltage are shown in this photograph located above the wattmeter unit.

The power-limiting scheme in connection with the indicating equipment consists of a contact-making ammeter, Fig. 14, for each substation with its coil connected in series with the pilot wire circuit so that when the current in the pilot wire decreases to a certain predetermined point, 0.237 amp., contact is made and resistance inserted in the exciter circuit supplying excitation to the separately excited direct-current generators by means of a motor operated rheostat, Fig. 12. These rheostats have sufficient resistance to lower the substation voltage to a minimum of 2100 volts. When contact is made by the contact-making ammeter, the voltage of the

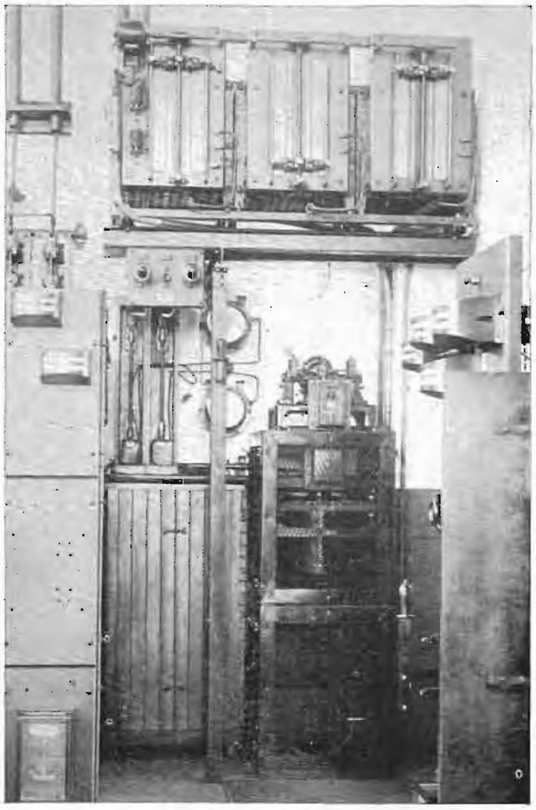

Fig. 12. Complete Motor Operated Contact Making Wattmeter Unit and Motor Operated Generator Voltage Lowering Rheostats Located Above the Wattmeter in the Janney Substation

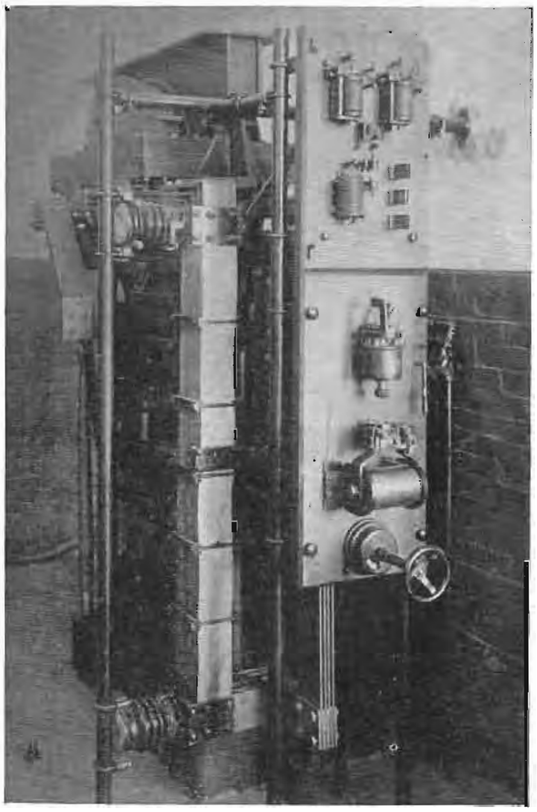

Fig. 13. Main Negative Shunt Used with Relays Shown in Fig. 14

substation is decreased and the resulting slowing down of the trains reduces the total input of the substation to a value below the predetermined peak setting. When the total load becomes less than the peak setting, the contact-making ammeter will make contact on the other side and bring the voltage of the substation back to normal. A secondary current coil forms part of the contact-making ammeter and is energized with current from a direct-current shunt, Fig. 13, in the ground or negative side of the 3000-volt substation, so that the heavily loaded substations have their voltage decreased slightly before those with lighter loads. If the total alternating-current input is beyond that covered by the power contract, or the limit determined by the train dispatcher, the voltage of all of the substations will be decreased until the total input reaches the amount decided upon.

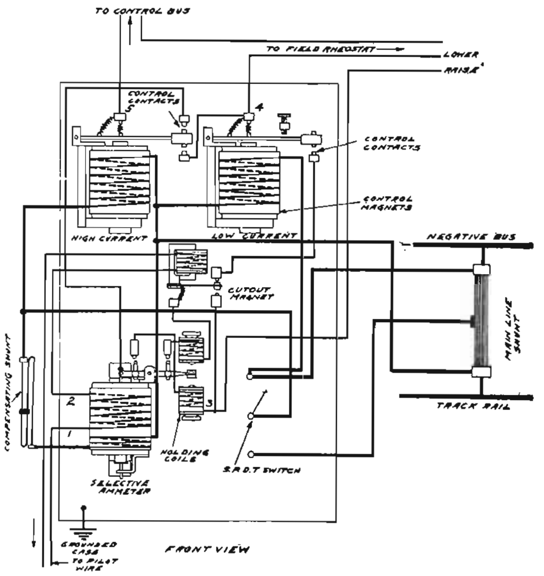

Fig. 14. Connections of Contact-making Ammeter Panel

An overload and an underload relay are also connected across the current shunt. The underload relay is calibrated to make contact at about one-half load on a substation so that the limiting equipment is inoperative until the load is greater than this amount. The overload relay is set to take control of the motor-operated rheostats at three times load and prevents the load going above this amount by lowering the voltage independently of the power-limiting equipment which transfers some of the load to the substations on either side.

If the power demand should be greater than the peak limit while a locomotive is regenerating through a substation, the reverse-current relay, at the bottom of the panel, Fig. 13, in each substation (primarily used to give correct field connections of the synchronous motor exciter) is also arranged to open one of the control circuits so that the voltage lowering rheostats are inoperative.

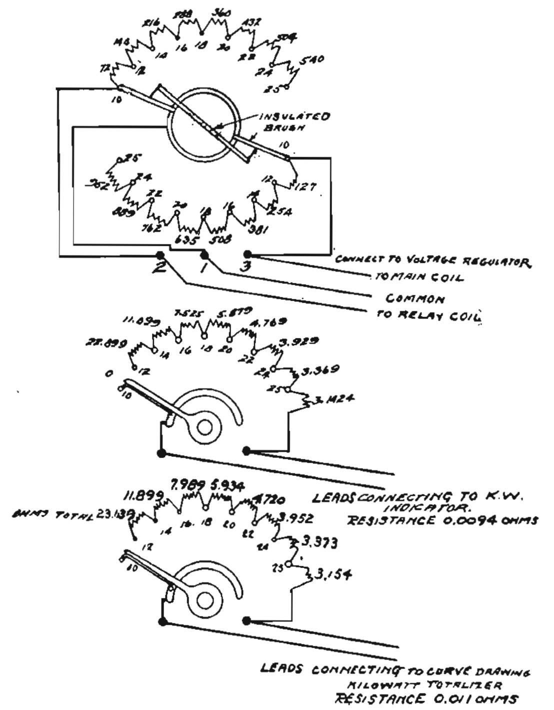

Fig. 15. Connections of Complete Kilowatt Limit Adjusting Rheostats

With this arrangement the potential is held constant at 3000 volts. If the voltage should be below normal, due to operation of the power-limiting equipment, and regeneration should occur, the voltage is automatically brought back to 3000 volts and held at this value.

The shunt for operating the underload and the overload relays, and the selective coil of the contact-making ammeter is also shown in Fig. 13.

The maximum kilowatt peak limit or kilowatt setting can be changed at any time by the train dispatcher to take care of unusual congestion or other requirements by simply varying the voltage across the pilot wire in the definite steps shown in Table I by means of the handwheel *F*, Fig. 6. The simplicity of this arrangement is due to the fact that the higher the voltage the greater the number of ohms which must be inserted to reduce the pilot wire current to 0.237 amp. This is clearly shown in Table II.

The different kilowatt settings are therefore obtained with certain definite voltages which must be held accurately by the voltage regulator. This is accomplished by the rheostat handwheel *F*, Fig. 6, and the connections, Fig. 15, which change the setting of the voltage regulator. If the voltage held should vary slightly, closer adjustment can be made with rheostat *G*. These main voltage points are marked in red on the scale of the indicating voltmeter to assist in obtaining correct setting.

Due to the necessity of reducing the pilot wire current to the same value, the kilowatt totalizing meters, which are ammeters calibrated in kilowatts, must record correctly the total kilowatts although finally carrying the same amperes, i.e., 0.237. This is accomplished by gearing the several rheostats together with a common rheostat handwheel *F*, Figs. 6 and 15. This handwheel which changes the voltage through the regulator by definite steps also changes at the same time, by definite increments, the resistance across the coils of the two kilowatt meters, thus altering the current required to give any definite scale indication in the ratio of the change made at the same time in the pilot wire voltage. By this means 0.237 amp., which is the point at which the contact-making ammeter makes contact, can be made to represent 10,000 kw., 12,000, up to 25,000 kw. by simply turning the rheostat handwheel to definite points plainly marked on the escutcheon, correctly connecting the three different circuits.

It was thought that it might be necessary actually to calibrate the kilowatt meters on the ground after being installed by means of the standard curve-drawing meters in the different circuits but this was found unnecessary as the check readings, taken with all the equipment installed exactly as laid out, indicated that these meters are as accurate if not more so than the standard meters. Table III gives a record of a large number of readings taken before the contact-making wattmeters were changed to the low side of the step-down transformers. These readings show remarkable accuracy as no special pains were taken to synchronize the clocks of the different curve-drawing meters which probably accounts for some of the greater variations. It should be kept in mind that this record was made when equipment was first placed in operation and that the four feeding points were located along the railway line over a distance of more than 200 miles, being the first time that power supplied by more than one line was added and recorded on one meter over such a great distance. It is therefore evident that the power supplied by any number of transmission lines over practically any reasonable distance can be accurately indicated and recorded in this manner.

The curve-drawing kilowatt totalizing meter reaches correct readings more quickly than the standard curve-drawing switchboard-type wattmeters in the substation and consequently gives a better detailed record of the load.

The lowering of the trolley voltage in the substation is accomplished slow enough, by proper speed of the motor-operated field rheostat, as not to affect the operation of the trains objectionably, the only result being a gradual slowing down of the train.

TABLE II

CURRENT IN PILOT WIRE CORRESPONDING TO VARIOUS POWER LIMITS

Kilowatt Peak Limit	Volts Across Pilot Wire	KILOWATT SCALE													
		0	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	25000
		Milli-amperes													
25000	1200	353.0	339.5	327.2	315.8	305.1	295.0	285.5	277.0	268.5	261.0	253.5	246.5	240.0	**237.0**
24000	1184	348.5	335.0	323.0	311.6	301.0	291.0	282.0	273.3	265.0	257.5	250.0	243.0	**237.0**	233.7
22000	1152.5	339.0	326.5	314.5	303.5	293.0	283.5	274.5	266.0	258.0	250.5	243.5	**237.0**	230.5	227.5
20000	1121	330.0	317.5	306.0	295.0	285.0	275.6	267.0	259.0	251.0	244.0	**237.0**	230.5	224.0	221.0
18000	1089.5	320.5	308.5	297.0	287.0	277.0	268.0	259.5	251.5	244.0	**237.0**	230.5	224.0	218.0	215.0
16000	1058.5	311.0	299.5	288.5	278.5	269.0	260.0	252.0	244.0	**237.0**	230.0	224.0	218.0	212.0	209.0
14000	1027	302.0	290.5	280.0	270.0	261.0	252.0	244.5	**237.0**	230.0	223.0	217.0	212.0	205.5	203.0
12000	995.5	293.0	281.5	271.0	262.0	253.0	244.7	**237.0**	230.0	223.0	216.0	210.5	205.5	199.0	196.5
10000	964	283.5	272.5	263.0	253.5	245.0	**237.0**	230.0	222.5	216.0	209.5	204.0	198.0	193.0	190.5
Resistance (ohms)..		3400	3533	3667	3800	3933	4067	4200	4333	4467	4600	4733	4867	5000	5067

Additional power limiting is also obtained by instructing the freight engineers to drop back to the series connection of the locomotive motors if very low trolley voltage is indicated by the voltmeters in each locomotive cab.

Several different peak settings have been tried out from time to time during the last two years to ascertain the correct peak limit for different service conditions. Some of the lower settings slowed down the trains to such an extent as to be objectionable on account of overtime of train crews or delay in passenger trains. It was found that peak settings could be obtained which would prevent excessive peaks and still maintain good operating voltage practically all the time, giving load-factors which have never before been obtained for similar service in electric

TABLE III

COMPARISON OF CURVE-DRAWING KILOWATT TOTALIZING METER INDICATION WITH SUMMATION OF READINGS OF THE SUBSTATION CURVE-DRAWING WATTMETERS, APRIL 16, 1918

Time	Morel	Piedmont	Josephine	Two Dot	Summation Curve Drawing Meters	Curve Drawing Kilowatt Totalizer
8:00 a.m.	0	1000—	2500—	5800	2300	2100
8:30	200	200—	3400—	5800	2500	2800
10:00	0	1500	2800—	10000	7700	7750
10:30	1000	800	2800—	9000	8000	8000
11:30	2800	1000	2400—	10500	11900	11800
11:30	3000	1600	2600—	10000	12000	11800
12:00 noon	4000	3000	2800—	9600	13800	13300
12:30 p.m.	1000	2000	2600—	9000	12000	11700
1:00	1500	1600	2800—	10800	11100	11700
1:30	2600	1800	2500—	9800	11700	11300
2:00	5400	3000	3000—	11700	17100	17500
2:30	2800	0	3200—	10800	10400	10900
3:00	0	500—	2600—	11000	7900	7800
3:30	400—	500—	3200—	7900	3800	3500
4:00	1500	500—	3000—	5900	3900	3900
4:30	1500	500—	2400—	6900	5500	6200
5:00	1700	0	2200—	8100	7600	7500
6:30	4000	1500	2600—	10100	13000	13500
7:00	1000	1600	2800—	7100	6900	7600
7:30	3100	500	2200—	7000	8400	6600
8:00	4000	0	2600—	7000	8400	8500
9:00	4000	400—	3000—	7900	8500	9000
10:00	4000	0	3000—	7500	8500	9000
11:00	2000	0	2200—	8900	8700	7000
11:30	3200	0	2000—	8700	8900	9400
12:00	3600	0	3000—	7500	8100	8000
Average.....	....	....	....	....	8792	8775

—Indicates power fed back to the power company.

TABLE IV

SUMMARY OF PERFORMANCE OF POWER-LIMITING AND INDICATING SYSTEM FOR SIX MONTHS—ROCKY MOUNTAIN DIVISION

Date 1919	Time Peak Limit Hours	Per Cent Peak Time of Actual Running Time	Load-factor
April..	43.6	6.4	59.3
May..	32.6	4.6	56.1
June..	6.1	1.6	56.5
July..	4.6	0.77	55.6
August..	26.7	4.1	54.7
September..	65.8	9.5	58.8
Average..	....	....	56.8

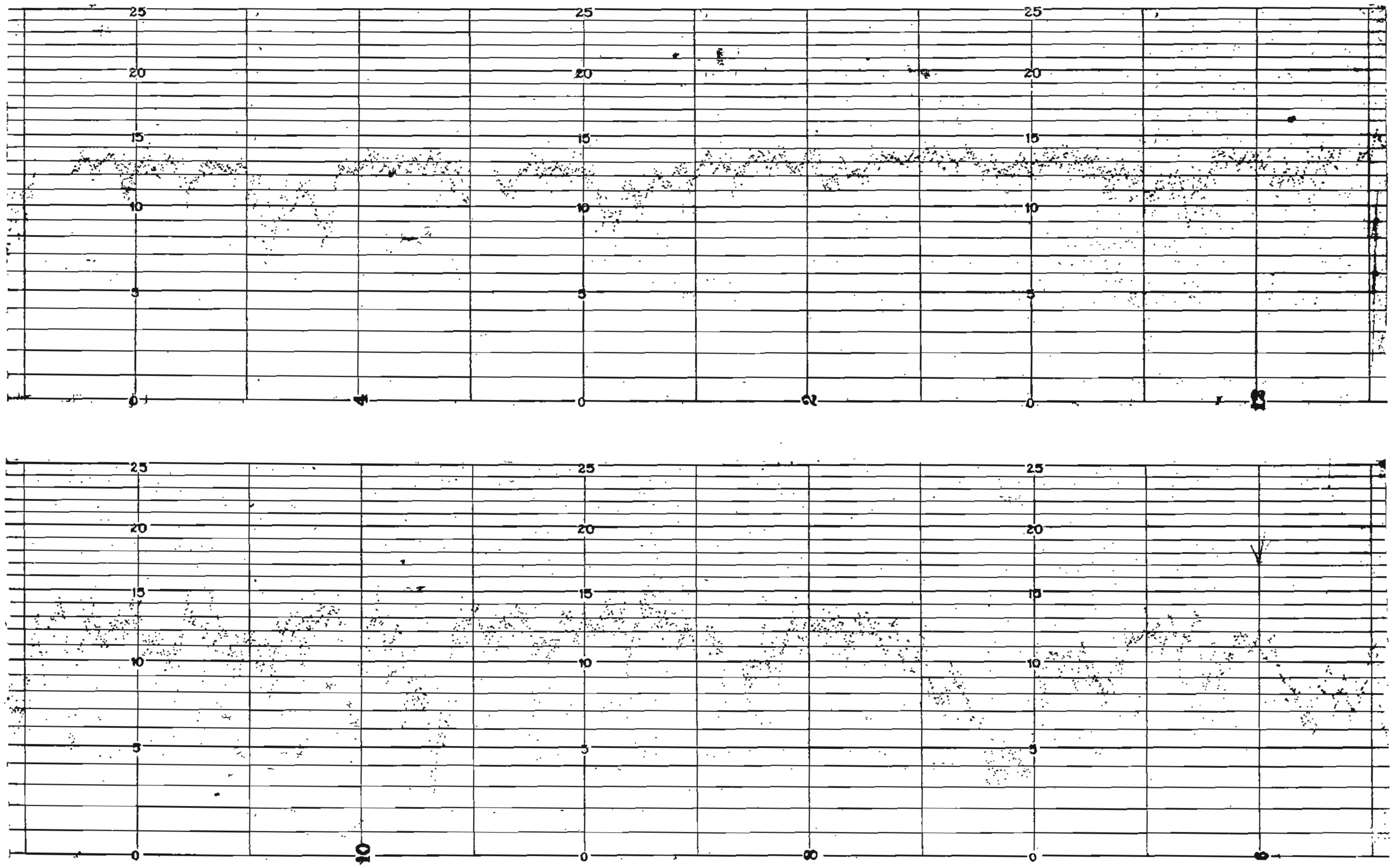

Fig. 16. Two Sample Sections of Record Made by the Curve Drawing Totalizing Tapalog Wattmeter on the C., M. & St. P. Rwy. These show how closely the power-limiting equipment holds a continuous heavy demand within the peak setting of 14,000-kw.

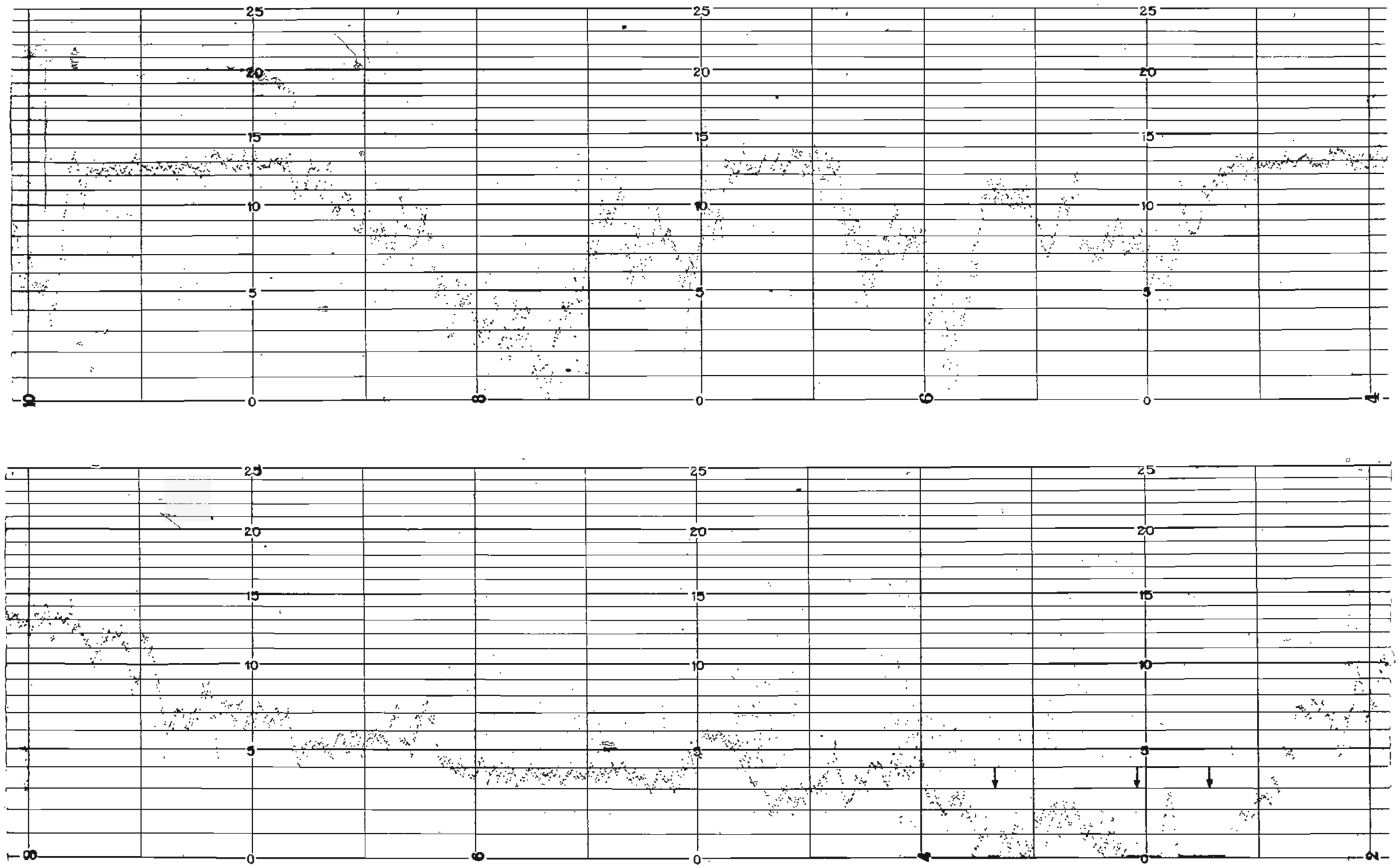

Fig. 17. Sample Records Similar to Those in Fig. 19, except that these show a very variable load. The vertical arrows on the lower record indicate points of regenerated power. The amounts are not recorded as the meter is not capable of giving negative indications

railway operation. The peak limit was set at 14,000 kw. for the Rocky Mountain Division on April 1, 1919, and operation has been very satisfactory on this basis. The average load-factor per month for six months is given in Table IV, or a total average load-factor of 56.8 per cent, which is a unique showing for railway operation and which confirms the wisdom of the railway company in specifying and installing the equipment described in this article.

The railway company pays 0.536 cents per kilowatt-hour for 60 per cent of the peak irrespective of whether this amount is actually used. The load-factor maintained is so near 60 per cent that the increase in cost of power or the cost of power not used is very slight. With increase in the number of trains, the load-factor will be raised and no difficulty should be experienced in holding a load-factor of 60 per cent or better.

Short lengths of the curve-drawing totalizing wattmeter record are shown in Figs. 16 and 17. These records were taken with a peak setting of 14,000 kw. and show how close the peak power consumption is kept to this point. One section shows an input of 14,000 kw. for several hours, varying from this amount to zero reading or reversal of energy, all of the stand-by losses being supplied by power regenerated by the locomotive.

If the power-limiting feature is removed, peaks as great as 7000 to 8000 kw. above the 14,000 kw. limit result.

One of the great indirect benefits obtained is the valuable assistance the indicating equipment gives the train dispatcher in dispatching trains in such a manner as not to give excessive peaks and thereby lowering the voltage due to the power-limiting equipment. By careful train dispatching so that one train is ascending the mountain grade while another train is descending, it is possible to assist the automatic equipment in maintaining a good load-factor very materially and to greatly increase the efficiency of the general operation of the railroad.

Great credit is due Messrs. E. S. Johnson, J. R. Craighead, J. B. Taylor, and E. J. Thiele for valuable suggestions, improvements, and assistance in working out the details of the great number of new and untried features

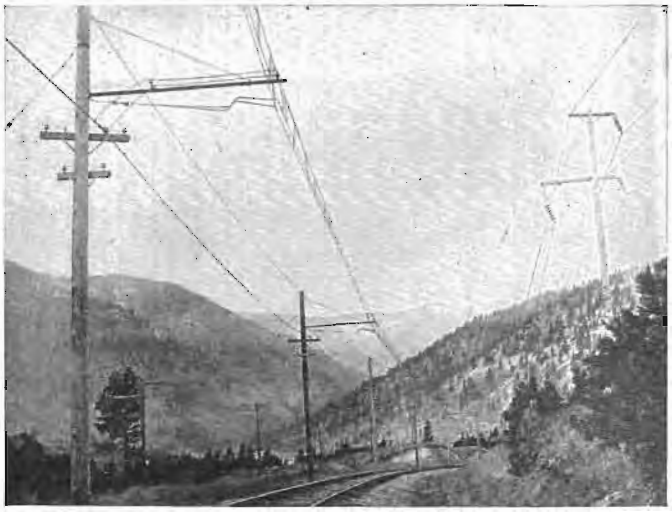

Fig. 18. View Taken on the Missoula Division of the C., M. & St P. Rwy. The lower cross arms on the poles at the left carry the power-limiting and indicating pilot wires