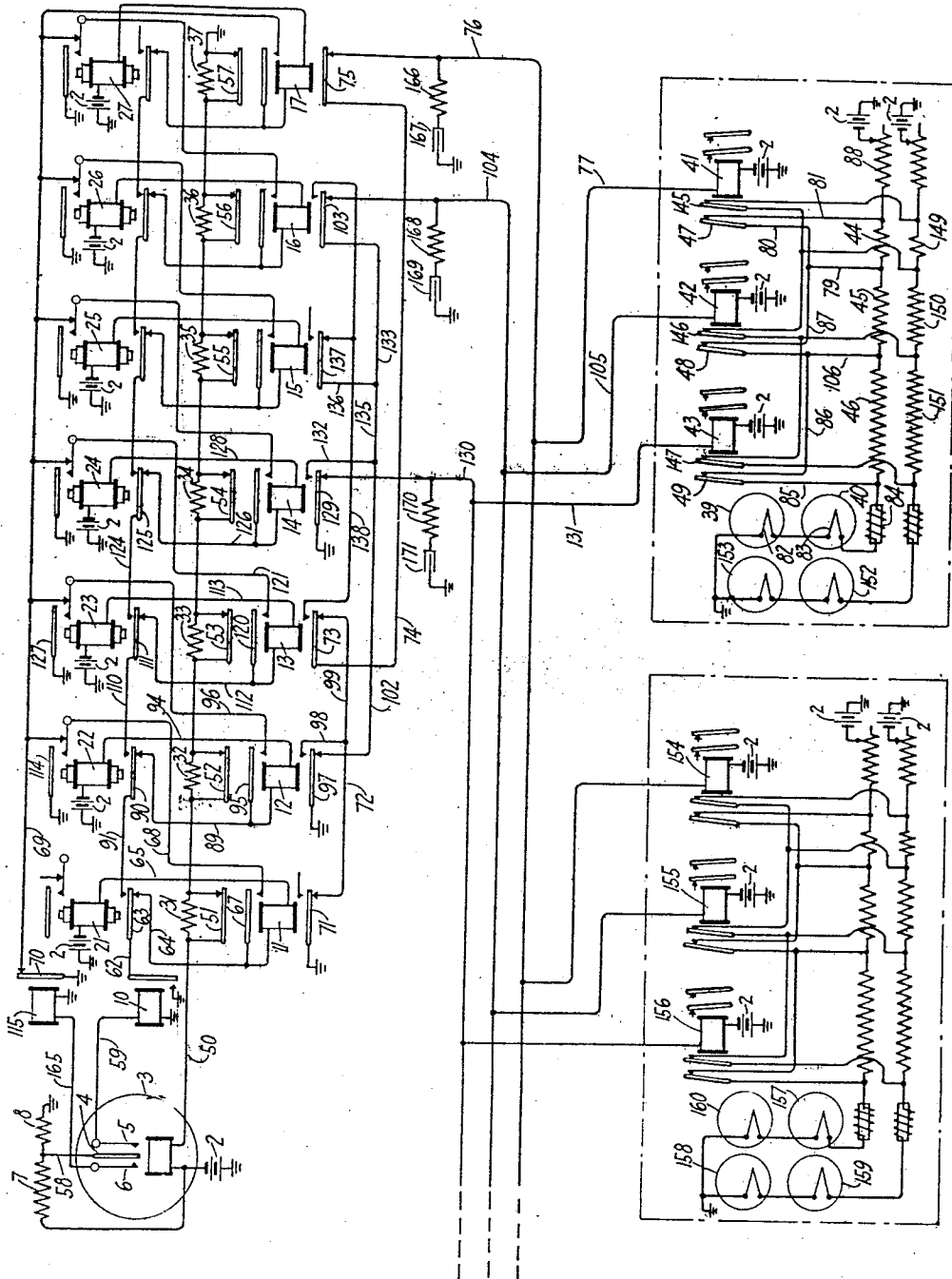


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R. D. CONWAY.
ELECTRIC REGULATOR.
FILED JULY 24, 1919.



Inventor:
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by *J. E. Roberts* Att'y.

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UNITED STATES PATENT OFFICE.

ROY D. CONWAY, OF CHATHAM, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

ELECTRIC REGULATOR.

Application filed July 24, 1919. Serial No. 313,032.

To all whom it may concern:

Be it known that I, ROY D. CONWAY, a citizen of the United States, residing at Chatham, in the county of Morris, State of New Jersey, have invented certain new and useful Improvements in Electric Regulators, of which the following is a full, clear, concise, and exact description.

This invention relates to arrangements for regulating an electrical characteristic of a circuit, such as the intensity of current flowing therethrough. One of the objects of the invention is to provide a method and means for insuring a constant flow of current over a circuit. Another object consists in providing means for automatically increasing the resistance in a circuit whenever the current flow therethrough has a tendency to increase, and also means for automatically reducing the resistance in said circuit as the current flow decreases. A further object consists in the provision of a method and means for cutting in or out resistance in a circuit by successive steps in order to hold constant an electrical characteristic of a portion of the circuit. Other objects of this invention will appear in the detailed description to be given later.

It has often been found desirable to associate with a work circuit including translating devices such, for example, as a circuit including the filaments of a vacuum tube repeater, an arrangement for regulating the current flow therethrough. This is because the voltage at the source supplying the electrical current for the circuit may have a tendency to vary beyond the limits within which satisfactory operation of the apparatus will result. As it has been found that a vacuum tube repeater will give better service if the current flow in its filament heating circuit remains constant, the regulating apparatus comprising this invention has been provided.

The regulating apparatus of this invention includes a voltmeter relay sensitive to slight variations in voltage, the winding of which is connected to the source which supplies current for the work circuit. An increase in the voltage in this source will cause a circuit to be closed over the needle and one of the contacts of the voltmeter thereby operating resistance varying mechanism to add a certain amount of resistance in series with the winding of the voltmeter relay and additional resistance to the work circuit. If the

resistance thus added to the voltmeter circuit and the work circuit, is insufficient to counterbalance the increase in current due to the change in voltage, the voltmeter needle will not fall back to neutral position, but will serve to hold closed the circuit over the contact of the voltmeter. Accordingly, the resistance varying mechanism will continue to operate and will add further resistance units to the circuit including the voltmeter winding and the work circuit, until the increase in current flow has been counterbalanced and the needle returned to neutral position. If the current flow from the source decreases, a circuit is closed over the needle and another contact of the voltmeter which serves to operate the resistance varying mechanism to reduce the resistance in the voltmeter circuit and the work circuit in proportion to the decrease in voltage.

In the preferred form, this resistance varying mechanism comprises a series of relays under the control of the contacts of the voltmeter. The relays of this series are adapted to control the association with the voltmeter circuit of a plurality of resistance units and are also adapted to control an additional series of normally energized relays which control the association with the work circuit of a plurality of resistance units. Means are also provided for insuring the successive action of these two series of relays so that only one resistance may be cut in or out of the voltmeter circuit at one time. Preferably this is accomplished by providing a series of slow-acting relays for transferring the control of the contacts of the voltmeter relay from one of said resistance controlling relays to the next in order as the voltage supply changes.

This invention may now be more fully understood from the following detailed description taken in connection with the accompanying drawing which illustrates the preferred form of the circuit arrangements of this invention.

Connected to a battery 2 is a voltmeter relay 3 which has a needle 4 between two stationary contacts 5 and 6. Since these contacts are extremely delicate and easily burned out, needle 4 is connected to an intermediate point of a circuit containing the high resistances 7 and 8 and source of voltage 2, so that only a fraction of the total potential of battery 2 may be applied to the voltmeter

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needle in the case where the total potential of battery 2 would be injurious to the contacts if applied directly. Under the control of the voltmeter needle 4 and contact 5 is a relay 10 which controls the successive operation of the relays in the two series 11 to 17 inclusive and 21 to 27 inclusive. Each of the relays in the series 21 to 27 inclusive is a slow-acting relay designed so that it will not operate to open or close its contacts until after its corresponding relay in the series 11 to 17 inclusive has operated.

The successive operation of the relays 11 to 17 inclusive serves to add to the winding of the voltmeter relay, the resistances 31 to 37 respectively by the breaking of shunt paths around said resistances. These resistances have a value predetermined with respect to the adjustment of the contacts of the voltmeter relay. Under the control of the movable contacts of relays 11 to 17 inclusive, are a series of normally energized relays 41, 42 and 43 which, by their movable contacts 47, 48 and 49 in turn control resistances 44, 45 and 46 which are included in the heating circuit of the filaments of the vacuum tube repeaters 39 and 40. In the specific arrangement shown, resistance 46 should be four times the value and resistance 45 twice the value of resistance 44 in order to obtain various combinations of these three resistances taken separately or together that will give seven equal steps in the increase or decrease of the amount of resistance in the filament circuit, since in the specific embodiment shown, seven steps are provided for the increase or decrease in the resistance in the circuit of the voltmeter relay winding. The manner in which this is performed will be explained later in detail.

The operation of the arrangements of this invention is as follows: The circuit normally closed through the winding of the voltmeter relay 3 is from ground, battery 2, winding of voltmeter 3, conductor 50 and movable contacts 51 to 57 inclusive to ground. An increase in the voltage of the source 2 will be indicated by a deflection to the right of the needle of the voltmeter relay thereby closing the following circuit: from ground, battery 2, resistance 7, conductor 58, needle 4, contact 5, conductor 59, and winding of relay 10 to ground. The closing of the above described circuit energizes relay 10 which pulls up its movable contact and closes the following circuit: from ground, movable contact of relay 10, conductor 62, movable contact 63, conductor 64, winding of relay 11, conductor 65, winding of relay 21 to battery and ground. This energizes relay 11 which pulls up its movable contact 67 and is locked up over the following circuit: from ground and battery, winding of relay 21, conductor 65,

winding of relay 11, movable contact 67, conductors 68, 69 and movable contact 70 of relay 115 to ground. The energization of relay 11 also serves to pull over its movable contact 51 thereby breaking the short-circuit around resistance 31 so that the closed circuit for the winding of the voltmeter relay may be traced from ground, battery 2, winding of voltmeter relay 3, conductor 50, resistance 31 and movable contacts 52 to 57 inclusive to ground. If the addition of resistance 31 is sufficient to counter-balance the increase in the voltage of source 2, the needle of the voltmeter relay will return to neutral position and thus open the circuit formerly closed by the operation of relay 10. As the relay 11 was locked up as formerly pointed out, it holds open the following normally closed circuit by pulling up its lower movable contact 71: from ground, movable contact 71, conductor 72, movable contact 73, conductor 74, movable contact 75, conductors 76 and 77, winding of relay 41 to battery and ground. The opening of this circuit by the energization of relay 11, deenergizes relay 41 and opens the shunt around resistance 44 which normally consists of conductors 79, 80, movable contact 47 and conductor 81. The heating circuit for the filament of the vacuum tubes 39 and 40 may then be traced as follows: from ground, filaments 82 and 83, choke coil 84, conductor 85, normally closed movable contact 49, conductor 86, normally closed movable contact 48, conductors 87 and 79, resistance 44, adjustable resistance 88 to battery 2 and ground. Thus it is apparent that the deenergization of relay 41 has added resistance 44 to the work circuit to counterbalance the increase in voltage of battery 2 thereby preventing any increase in the value of the heating current for the filaments 82 and 83. After the relay 11 has pulled up its three movable contacts and has been locked through the circuit described above, the slow-acting relay 21 attracts its movable contact 63 so as to disconnect the windings of relays 11 and 21 from the armature of relay 10 and to connect instead the windings of relays 12 and 22 thereto through conductors 94 and 89, movable contact 90, conductor 91, movable contact 63 to the movable contact of relay 10. This change therefore makes relays 12 and 22 responsive to the energization of relay 10.

If the addition of the resistance 31 to the circuit including the voltmeter relay 3 is not sufficient to counter-balance the increase in the voltage of the battery 2, the needle of the voltmeter relay will not return to neutral position but will remain deflected to the right and the relay 10 will remain energized and after the slow-acting relay 21 has changed the relay under the control of relay 10

10 from relay 11 to relay 12, the following circuit will be closed: from ground, movable contact of relay 10, conductor 62, movable contact 63, conductor 91, movable contact 5 90, conductor 89, winding of relay 12, conductor 94, winding of relay 22 to battery and ground. The closing of this circuit will energize relay 12 which will pull up its armatures and become locked up over the 10 following circuit: from ground and battery, winding of relay 22, conductor 94, winding of relay 12, movable contact 95, conductors 96 and 69 to movable contact 70 of relay 115 and ground. The actuation of relay 12 15 by pulling up its armature 52 opens the short-circuit around resistance 32 so that the circuit of the voltmeter relay winding may now be traced from ground, battery 2, winding of voltmeter relay 3, conductor 50, 20 resistances 31, 32 and movable contacts 53 to 57 inclusive, to ground. Thus the circuit of the voltmeter relay winding now includes resistance 32 as well as resistance 31. If the addition of these two resistances is sufficient to counter-balance the rise in voltage 25 of battery 2, the needle of the voltmeter relay will return to neutral position and thus open the circuit formerly closed by the operation of relay 10.

30 As the relay 12 was locked up, as formerly pointed out, its lower movable contact 97 has been pulled over to close the following circuit: from ground, movable contact 97, conductors 98, 99, movable contact 73, conductor 74, movable contact 75, conductors 35 76, 77, winding of relay 41 to battery and ground. The closing of this circuit energizes relay 41 which pulls over its movable contact 47 to close the shunt path around resistance 44. From the pulling up of the armature of 40 the movable contact 97 of relay 12 the following normally closed circuit is opened: from ground, movable contact 97, conductor 102, movable contact 103, conductors 104 and 105, winding of relay 42 to battery and 45 ground. The opening of this circuit deenergizes relay 42 thereby releasing its movable contact 48 and consequently opening the shunt path around resistance 45 which normally includes conductor 106, movable contact 48, and conductors 87 and 79. The energization of relay 12 therefore deenergizes relay 42 to open the shunt path around 50 resistance 45 and subsequently energizes relay 41 to close the shunt path around resistance 44. The heating circuit for filaments 82 and 83 may now be traced as follows: from ground, filaments 82 and 83, choke coil 84, conductor 85, movable contact 49, conductors 86 and 106, resistance 45, conductors 60 79 and 80, movable contact 47, conductor 81, resistance 88 to battery and ground. Thus it is seen that the energization of relay 12 short-circuits resistance 44 and automatically puts instead in the heating circuit

a resistance 45 which is twice as large in value as resistance 44, thereby counterbalancing the change of the voltage of source 2 and maintaining constant current through the filaments.

70 Subsequent to the actuation of relay 12, the slow-acting relay 22 pulls up its lower armature 90 so as to remove the control of relay 10 from relay 12 to relay 13 by including the winding of relay 13 by the following circuit: from movable contact of relay 10, conductors 62, 91, movable contact 90, conductor 110, movable contact 111, conductor 112, winding of relay 13, conductor 113, winding of relay 23 to battery and 75 ground. Winding of relay 22 by pulling up its movable contact 114 removes the locking circuit for relay 11 from under the control of movable contact 70 of relay 115 by causing relay 11 to be locked up instead 85 over the following circuit: from ground, and battery, winding of relay 21, conductor 65, winding of relay 11, movable contact 67, conductor 68, movable contact 114 to ground. Thus it is seen that the energization of relay 90 11 ceases to be under the control of relay 115 when relays 12 and 22 have been energized.

However, if the increase in the voltage of source 2 has not been counter-balanced by 95 including in the voltmeter circuit, the resistance elements 31 and 32, the voltmeter relay needle will not return to neutral position, but will remain deflected to the right. Accordingly, relay 10 will keep its movable 100 contact pulled over and after slow-acting relay 22 has operated will energize relays 13 and 23 over the following circuit: from ground, movable contact of relay 10, contact 63, conductors 91, 110, movable contact 111, 105 conductor 112, winding of relay 13, conductor 113, winding of relay 23 to battery and ground. The closing of this circuit will energize relay 13 which will pull up its movable contacts and become locked up over the 110 closing of the following circuit: from ground and battery, winding of relay 23, conductor 113, winding of relay 13, movable contact 120, conductors 121 and 69 to movable contact 70 of relay 115 to ground. The 115 actuation of relay 13 also serves to open the short-circuit around the resistance 33 thereby increasing the amount of resistance in the circuit of the winding of the voltmeter relay. If the addition of resistance 33 is sufficient to counter-balance the change in the 120 voltage of source 2, the voltmeter relay needle will return to neutral position and deenergize relay 10.

Since relay 13 has been locked up, the 125 closing of its movable contact 73 breaks the following normally closed circuit: ground, movable contact 97, conductors 98, 99, movable contact 73, conductor 74, movable contact 75, conductors 76, 77, winding of relay 130

41 to battery and ground. The opening of this circuit deenergizes relay 41 and consequently opens the shunt path around resistance 44. The energization of relay 13, however, does not effect relay 42 which has been previously deenergized by the operation of relay 12 so that with the operation of relay 13, the heating circuit for filaments 82 and 83 includes resistance 44 as well as resistance 45, which was previously added.

Subsequent to the operation of relay 13, relay 23 operates to pull over its movable contact 111 to change the control of relay 10 from relay 13 to relay 14, by making the following circuit: movable contact of relay 10, conductors 62, 91, 110, 124, movable contact 125, conductor 126, winding of relay 14, conductor 128, winding of relay 24 to battery and ground. The operation of relay 23, by pulling up its movable contact 127, removes the control of the locking circuit of relays 12 and 22 from under the control of the movable contact 70 by locking these relays instead over the following circuit: ground and battery, winding of relay 22, conductor 94, winding of relay 12, movable contact 95, conductor 96, movable contact 127 to ground. Relay 12 therefore ceases to be under the control of movable contact 70 when relays 13 and 23 have been energized.

If the addition of resistances 31, 32 and 33 does not counter-balance the change in voltage of source 2, the voltmeter relay needle will remain deflected to the right and relay 10 will energize relays 14 and 24. Relay 14 will be locked up over contact 70 of relay 115 and will include resistance 34 in circuit with the winding of the voltmeter relay. The pulling up of the movable contact 129 of relay 14 will open the following circuit: ground, movable contact 129, conductors 130, 131, winding of relay 43 to battery and ground. The opening of this circuit will deenergize relay 43 and consequently break the shunt path around resistance 46 which normally consists of conductor 85, movable contact 49, conductors 86 and 106. The pulling up of movable contact 129 will also close the following circuit: ground, movable contact 129, conductors 132, 133, movable contact 103, conductors 104, 105, winding of relay 42 to battery and ground. The pulling up of movable contact 129 also closes the following additional circuit: ground, movable contact 129, conductors 132, 135, 136, movable contact 137, conductor 138, movable contact 73, conductor 74, movable contact 75, conductors 76, 77, winding of relay 41 to battery and ground. Thus it is seen that the operation of the relay 14 deenergizes relay 43 so that resistance 46 is added to the heating circuit of filaments 82 and 83. Relays 41 and 42 are also energized to close shunt paths around resistances 44 and 45 so that with the operation of the relay 14, only

resistance 46 is included in the filament heating circuit. Resistance 46, as stated above, is equal to four times the value of resistance 44.

After relay 14 has been energized, relay 24 will operate to include the winding of relay 15 in circuit with the movable contact of relay 10 and will also operate to remove the locking circuit for relay 13 from under the control of the movable contact of relay 115.

If the voltage of source 2 increases still further, relay 10 will cause relay 15 to be energized which will include resistance 35 in circuit with the voltmeter relay winding so as to counter-balance the increase in voltage of source 2. The energization of relay 15 will also open the following normally closed circuit: ground, movable contact 129, conductors 132, 135, 136, movable contact 137, conductor 138, movable contact 73, conductor 74, movable contact 75, conductors 76 and 77, winding of relay 41 to battery and ground. The opening of this circuit deenergizes relay 41 and causes resistance 44 to be included in the filament heating circuit so that with the operation of relay 15, resistances 44 and 46 are included in the filament circuit, while the shunt path around resistance 45 remains closed.

The actuation of relay 16 will by circuits similar to those already traced add resistance 36 to the voltmeter circuit, will keep open the shunt around resistance 46, will open the shunt around resistance 45 and will close the shunt around resistance 44, so that for the sixth step in the operation of the regulator resistances 46 and 45 will be included in the filament heating circuit while resistance 44 is short-circuited.

The operation of relay 17 will include resistance 37 in circuit with the winding of the voltmeter relay, will leave open the shunts to resistances 45 and 46 and will open the shunt to resistance 44, so that all three resistances 44, 45 and 46 are included in the filament heating circuit.

It is therefore seen that in the specific embodiment shown seven steps are provided for increasing the resistance in the work circuit or filament heating circuit for keeping the current constant thereto in spite of changes of voltage of its source of heating current.

It is also apparent that the other movable contacts of relays 41, 42 and 43 may control resistances included in other filament heating circuits to keep the current constant therethrough. Thus movable contacts 145, 146, 147 may be so connected as to control resistances 149, 150 and 151 which may be included one or more at a time in the filament heating circuit of tubes 152 and 153, these resistances being proportioned to each other in the same manner as resist-

ances 44, 45 and 46. It is apparent that the main conductors 76, 104 and 130 may be connected to other sets of relays similar to the set 41, 42 and 43 for controlling through the movable contacts of each set, the amount of resistance in still other filament circuits. Thus an additional set of relays 154, 155 and 156 is shown connected respectively to leads 76, 104 and 130 for controlling through their movable contacts the amount of resistance added to the filament heating circuits of other vacuum tubes such as 157, 160 and 158, 159. It is obvious that a very large number of sets of relays such as set 154, 155 and 156 may be connected to the main conductors 76 and 104, 130, all of the sets being controlled by the operation of relays 11 to 17 inclusive.

From the above described operation, it is seen that any rise in voltage of battery 2 which may be encountered may be compensated for to limit the current flow in the work circuit comprising the filaments of the vacuum tube repeaters. The current flow can be maintained within any desired limits by the use of a suitable number of steps, since it is obvious that this invention is not limited to the use of only seven steps in the operation and that the number of steps may be increased or decreased to meet the particular requirements of the work circuit to be controlled.

The above description describes the operation of the system for increases in voltage. A reversal of the process will occur if the voltage should fall in value. If, after the resistances 31 to 37 have been included in the voltmeter relay circuit and resistances 44, 45 and 46 have been included in the work circuit, the voltage of the source 2 should fall, the system operates to successively cut out of circuit, resistances 37, 36, 35, etc., until the decrease in voltage has been counter-balanced. At the same time a corresponding value of the resistance in the filament heating circuit is cut out to keep the current therethrough from decreasing.

The manner in which the system operates for decrease in voltage may be explained as follows: Suppose, for example, that the voltage of source 2 has increased to such a value that relays 11, 12 and 13 have been energized to include resistances 31, 32 and 33 in the circuit of the voltmeter relay winding in order to bring back voltmeter needle 4 to neutral position; and at the same time resistances 44 and 45 have been added to the filament circuit to maintain the filament current constant. Under this assumption, relays 21 to 23 inclusive would also have been energized so that the movable contact of relay 10 is now connected to the winding of relay 14 which is the next in series and disconnected from the winding of relay 13.

As has been traced before, relay 13 under these conditions is locked up over the following circuit: from ground, and battery, winding of relay 23, conductor 113, winding of relay 13, movable contact 120, conductor 121 and 69 to movable contact 70 of relay 115 and ground. If now the voltage of source 2 should decrease, the voltmeter needle would be deflected to the left and make contact with contact 6 thereby completing the following circuit: from ground, battery 2, resistance 7, conductor 58, contact 6, conductor 165, winding of relay 115 to ground. The completion of this circuit energizes relay 115 which pulls up its movable contact 70 thereby opening the locking circuit for relays 13 and 23 and deenergizing these relays. The deenergization of relay 13 causes movable contact 53 to short-circuit resistance 33 thereby decreasing the amount of resistance in circuit with the voltmeter relay winding.

If this reduction in resistance in the circuit of the voltmeter relay winding is sufficient to counter-balance the decrease of voltage of source 2, the needle of the voltmeter relay will return to neutral position and no further operation of the series of relays will take place. The deenergization of relay 13 also closes the following circuit: from ground, movable contact 97 of relay 12, conductors 98, 99, movable contact 73, conductor 74, movable contact 75, conductors 76, 77, winding of relay 41 and battery to ground. The completion of this circuit energizes relay 41 which pulls over its movable contacts and closes the shunt path about resistance 44 thereby decreasing the resistance in the filament heating circuit in proportion to the reduction of the resistance in the circuit including the voltmeter relay winding.

The deenergization of relay 23 allows its armature 111 to fall back so as to put the winding of relay 13 under the control of the movable contact of relay 10 so that relay 13 may again be energized in case the voltage of source 2 should increase. The falling back of armature 127 of relay 23 breaks the locking circuit for relays 12 and 22 which consisted of ground, battery, winding of relay 22, conductor 94, winding of relay 12, movable contact 95, conductor 96, movable contact 127 to ground, thereby causing the locking circuit for these relays to be traced instead from conductor 96 to conductor 69 and movable contact 70 to ground. This change of the locking circuit places relays 12 and 22 under the control of the movable contact 70 of relay 115.

If the decrease in voltage of source 2 has not been counter-balanced by the unlocking of relay 13 and the subtraction from the voltmeter relay circuit of the resistance 33, the needle of the voltmeter relay will remain deflected to the left and hold closed

the circuit through the winding of relay 115. The attraction of movable contact 70 of relay 115 will then break the locking circuit just described for relays 12 and 22 thereby
5 deenergizing these two relays. The deenergization of relay 12 will allow movable contact 52 to fall back so as to short-circuit resistance 32 thereby decreasing the resistance in the voltmeter relay circuit. The falling
10 back of movable contact 97 of relay 12 opens the following circuit: from ground, movable contact 97, conductors 98, 99, movable contact 73, conductor 74, movable contact 75, conductors 76, 77, winding of relay
15 41 to battery and ground. The falling back of movable contact 97 also closes the following circuit: from ground, movable contact 97, conductor 102, movable contact 103, conductors 104 and 105, winding of relay 42 to
20 battery and ground. The opening of the circuit including relay 41 will deenergize this relay and open the short-circuit for resistance 44. The making of the circuit including the winding of relay 42 will close the
25 short-circuit for resistance 45. It therefore follows that when relay 12 is deenergized, only resistance 44 is included in the heating circuit of the filaments.

The deenergization of relay 22 causes the
30 winding of relay 12 to be put under the control of relay 10 by closing the following circuit: movable contact of relay 10, conductor 62, movable contact 63, conductor 91, movable contact 90, conductor 89 to the
35 winding of relay 12, so that relay 12 may be energized again in case the voltage of source 2 should increase. The falling back of movable contact 114 of relay 22 places relays 11 and 21 under the control of relay 115
40 by locking the two relays over the following circuit: from ground and battery, winding of relay 21, conductor 65, winding of relay 11, movable contact 67, conductors 68 and 69 to movable contact 70 and ground.

45 If the voltage of source 2 should decrease still further, relay 11 will be deenergized cutting out resistance 31 in the voltmeter relay circuit and resistance 44 in the filament circuit. Or if, on the other hand, after
50 the deenergization of relay 12, the voltage of source 2 should increase, relay 12 would be energized, resistance 32 would be included in the voltmeter relay circuit and resistance 45, instead resistance 44, would be included
55 in the filament heating circuit.

This progression in either direction follows from the fact that at any time in the operation of the system, the last one of the relays 11 to 17 inclusive that is energized
60 is under the control of relay 115, so that the actuation of relay 115 for a decrease in voltage may serve to decrease the resistance in the voltmeter relay circuit and the filament heating circuit; and also the relay next
65 in advance of the last energized relay of

the series 11 to 17 inclusive is under the control of relay 10, so that further actuation of relay 10 may increase the resistance in the voltmeter relay circuit and the filament heating circuit for a further increase in voltage. 70
For example, if relays 11 to 14 inclusive and 21 to 24 have been energized, relays 14 and 24 are under the control of relay 115 since the locking circuit for the two relays includes the movable contact of relay 115. 75
Similarly the relays 15 and 25 which are the next two in advance to relays 14 and 24 would be under the control of relay 10. If the voltage of source 2 should then be increased, relays 15 and 25 would be energized, while if the voltage of source 2 was decreased, relays 14 and 24 would be deenergized. 80

In order to prevent any sudden change in current due to the opening or closing of
85 the movable contacts from injuring the contacts of the relays associated with the main conductors 76, 104 and 130, each of these conductors is provided with an alternating current path to ground consisting respectively of resistance 166 and condenser 167, resistance 168 and condenser 169, and resistance 170 and condenser 171. 90

While this invention has been disclosed in particular forms which have been found
95 desirable, it will be understood that it may be embodied in many and widely different forms without departing from the spirit of this invention, as defined in the appended claims. 100

What is claimed is:

1. In a system of distribution, a source of electrical energy, a conductor connected thereto including a plurality of resistance elements, shunt paths about said resistances, 105
another conductor connected to said source including a voltmeter and a plurality of resistance elements, short circuits about said second mentioned resistance, a series of relays, locking circuits for said relays, short
110 circuits about the windings of said relays, means under the control of said voltmeter for operating said relays and closing said locking circuits one at a time in order, means under the control of said voltmeter
115 for closing said second mentioned short circuits and unlocking said relays one at a time in a reverse order, and means under the control of said relays for opening or closing said shunt paths and said first mentioned
120 short circuits.

2. The method of regulating wherein is employed a circuit to be regulated, a regulating element for said circuit, a second regulating element for said circuit, a control
125 means for said elements, a second control means for said elements, said method comprising controlling said first mentioned element at times in response to said first mentioned means, and at other times controlling
130

said first mentioned element in response to said second mentioned means and placing said second element under the control of said first means.

5 3. The method of correcting for changes in the voltage of a circuit wherein is employed a regulating element for said circuit, a control means for said element, a second control means for said element, said first
10 mentioned means normally controlling said first element, said method comprising causing said first mentioned means to operate said element for an increase in voltage, transferring the control of said element to
15 said second means after said increase in voltage, and causing said second means to operate said element for a decrease in voltage.

4. The method of correcting for changes
20 in voltage of a circuit wherein is employed a regulating element for said circuit, a second regulating element for said circuit, a control means for said elements, a second control means for said elements, said first
25 mentioned means normally controlling said first element, said method comprising causing said first mentioned means to operate said first element for an increase in voltage, transferring the control of said first element
30 to said second means after said increase in voltage, placing said second element under the control of said first means and causing said first means to operate said second element for a further increase in voltage.

35 5. A regulator comprising a regulating element, a plurality of relays for controlling said element, one of said relays being slow acting, and connections whereby the energization of said slow acting relay operates
40 another of said relays.

6. The combination of a solenoid, a regulating element controlled thereby, an impedance for connection in or out of circuit with said solenoid, and a slow-acting relay
45 controlling said impedance, said impedance remaining at times in circuit with said solenoid when said solenoid is subjected to current ineffective to produce regulation.

7. The combination of a solenoid, a regulating element controlled thereby, a resistance for connection in or out of circuit with said solenoid, a relay adapted to be made responsive to said solenoid for controlling
50 said resistance, and means comprising a slow acting relay for placing said first relay under the control of said solenoid.

8. A voltage responsive regulator comprising the combination of a solenoid, a resistance controlled thereby, an impedance
60 for varying the current through said solenoid, and a slow-acting relay controlling said resistance and said impedance.

9. The combination of a solenoid, a work circuit, a resistance in said work circuit
65 controlled by said solenoid, a second resist-

ance for connection in or out of circuit with said solenoid, a relay adapted to be made responsive to said solenoid for controlling said second resistance, and means comprising a slow-acting relay for placing said first relay under the control of said solenoid.

10. A regulator comprising the combination of a circuit, resistance elements of relative values 1, 2 and 4, and means responsive
75 to a condition of said circuit to combine said resistances for uniform graduation.

11. The combination of a circuit, a plurality of non-uniformly graded impedance elements adapted to be connected in said circuit, and automatic means for connecting
80 said impedance elements in said circuit in such combinations as to provide a uniform graduation thereof.

12. The combination of a circuit, a source
85 of voltage in said circuit, a plurality of non-uniformly graded impedance elements adapted to be connected in said circuit, and automatic means responsive to the voltage of said circuit for connecting said impedance
90 elements in said circuit in such combinations as to provide a uniform graduation thereof.

13. The combination of a circuit, a source of voltage in said circuit, means responsive to the voltage of said circuit for maintaining
95 substantially constant the current in said circuit, said means comprising a plurality of non-uniformly graded impedance elements, and means comprising a series of relays for connecting said impedance
100 elements in said circuit in such combinations as to provide a uniform graduation thereof.

14. The combination of a circuit, a source of voltage in said circuit, means responsive
105 to the voltage of said circuit for maintaining substantially constant the current in said circuit, said means comprising a voltmeter responsive to the voltage of said circuit, a plurality of nonuniformly graded
110 impedance elements adapted to be connected in said circuit, and means comprising a series of relays for connecting said impedance elements in said circuit in such combinations as to provide a uniform graduation
115 thereof.

15. The combination of a circuit, a source of voltage in said circuit, means responsive to the voltage of said circuit for maintaining substantially constant the current in
120 said circuit, said means comprising a series of impedance elements, each of said impedance elements, less one of the series, having a value substantially double the impedance of another of said impedance elements,
125 and means comprising a series of relays for connecting said impedance elements in said circuit in such combinations as to provide a uniform graduation thereof.

16. The combination of a circuit com- 130

prising an electro-responsive device, a series of relays for said circuit, a series of slow-acting relays for said circuit, moving contacts for said relays, said device controlling at one time a set of relays comprising a relay from each of said series, and a locking circuit for one of said relays of the set under the control of said device comprising a movable contact of a slow-acting relay of another set of said relays.

17. The combination of a circuit containing a source of voltage, and means responsive to the voltage in said circuit for maintaining substantially constant the current in said circuit, said means comprising a voltmeter, a series of relays for said circuit, a series of slow-acting relays for said circuit, movable contacts for said relays, a plurality of resistance units controlled by said relays, said voltmeter controlling at one time a set of relays comprising one relay from each of said series, and a locking circuit for one of said relays of the set under the control of said device comprising a movable contact of a slow-acting relay of another set of said relays.

18. A regulator comprising a solenoid, a source of energizing current for said solenoid, an element controlled by said solenoid, and means for automatically changing the calibration of said solenoid an amount dependent upon the intensity of the energizing force supplied to said solenoid, said means comprising impedance elements in series with said solenoid and movable contacts individual to said elements.

19. A regulator comprising a solenoid, an element controlled thereby, a source of energizing current for said solenoid, means for automatically changing the calibration of said solenoid an amount dependent upon the intensity of the energizing force supplied to said solenoid, said means comprising impedance elements and movable contacts individual thereto, solenoids for said contacts and connections whereby said solenoids are controlled by said first mentioned solenoid.

20. The combination of a circuit containing a source of voltage and an electro-responsive device, and means comprising a plurality of relays responsive to changes in said source of voltage for changing the calibration of said device, each of a plurality of said relays having a plurality of movable contacts.

21. The combination of a circuit containing an electro-responsive device and a source of voltage, a series of relays for said circuit, a series of slow-acting relays for said circuit, movable contacts for said relays, regulating elements controlled by said relays, said device controlling at one time a set of relays comprising a relay from each of said series, and means comprising a mov-

able contact controlled by one of the relays of the set normally under the control of said device for removing said last-named set from the control of said device and for placing another set under the control of said device.

22. A regulator comprising an electro-responsive device, a plurality of series of solenoids controlled thereby for progressive operation, and an armature controlled by one of said solenoids to remove a solenoid of each series from the control of said device and to place another solenoid of each series under the control thereof.

23. A regulator comprising an electro-responsive device, a plurality of series of solenoids controlled thereby for progressive operation, and an armature controlled by each solenoid of one series to remove a solenoid of each series from the control of said device and to place another solenoid of each series under the control thereof.

24. A regulator comprising regulating means, and control means therefor comprising a plurality of series of relays for progressive operation and connections whereby corresponding relays of each series are sequentially operated to vary the effectiveness of said regulating means.

25. A regulator comprising a plurality of series of relays for progressive operation and connections whereby corresponding relays of each series are sequentially operated.

26. A regulator comprising a plurality of regulating elements and control means therefor comprising a plurality of series of relays for progressive operation and connections whereby corresponding relays of each series are sequentially operated to vary the effectiveness of said regulating elements.

27. The combination of a plurality of work circuits, and means for holding substantially constant the current in said work circuits, said means comprising a solenoid having a plurality of armatures individual to said circuits.

28. The combination of a plurality of work circuits, means for supplying voltage to said work circuits, and means for holding substantially constant the current in said work circuits, said means comprising a voltmeter responsive to the voltage in said circuits, and a solenoid responsive to said voltmeter, said solenoid having a plurality of armatures individual to said circuits.

29. A regulator comprising an electro-responsive device, a plurality of relays controlled thereby for progressive operation, connections from said relays, and a plurality of circuits to be regulated, said circuits being responsive to the electrical condition of said connections.

30. A regulator comprising a voltage responsive device, a plurality of relays con-

trolled thereby for progressive operation, connections from said relays, and a plurality of circuits to be regulated, said circuits being responsive to the electrical condition of said connections.

31. A solenoid, an energizing circuit therefor, a plurality of relays controlled by said solenoid, a regulating element controlled by said relays, one of said relays operating only for an increase in the energization of said solenoid, another of said relays operating only for a decrease thereof, and means for automatically varying the calibration of said solenoid in response to changes in the energizing circuit of said solenoid.

32. A voltage-responsive regulator comprising a solenoid, an energizing circuit for said solenoid, a plurality of relays controlled by said solenoid, a regulating element controlled by said relays, one of said relays operating only for an increase in the energization of said solenoid, another of said relays operating only for a decrease thereof, and means controlled by said solenoid for varying the calibration of said solenoid.

33. A regulator comprising a solenoid, a plurality of relays controlled thereby, connections whereby one of said relays operates for an increase in the energization of said solenoid, another of said relays operating for a decrease in the energization of said solenoid, a second solenoid controlled at times by one of said relays and other times by said other relay, and a regulating element controlled by said second solenoid.

34. In a system of distribution, a source of voltage, a plurality of work circuits connected to said source, variable resistances individual to said circuits, means comprising a relay having an armature and responsive to an increase in voltage in said source for increasing the value of said resistances, and means comprising a second relay having an armature independently movable of said first armature and responsive to a decrease in voltage of said source for decreasing the value of said resistances.

35. In a system of distribution, a source of voltage, a plurality of work circuits connected in shunt to said source, variable resistances included in said circuits and individual to said circuits, means for maintaining substantially constant the current in said work circuits, said means comprising a relay having an armature and comprising means responsive to an increase in voltage of said source for increasing the value of said resistances, and means comprising a relay having an armature independently movable of said first armature and responsive to a decrease in voltage of said source for decreasing the value of said resistances.

36. In a system of distribution, a source of voltage, a plurality of work circuits connected in shunt to said source, a plurality of

resistances in each of said circuits and individual to said circuits, said resistances being adapted to be made effective or ineffective in said circuits, means responsive to a decrease in voltage of said source for rendering ineffective a resistance in each of said circuits, and means responsive to an increase in voltage of said source for rendering effective a resistance in each of said circuits.

37. In a system of distribution, a source of voltage, a plurality of work circuits connected in shunt to said source, a plurality of resistance elements in each of said circuits and individual to said circuits, said resistances being adapted to be made effective or ineffective in said circuits, and means for maintaining substantially constant the current in said work circuits, said means comprising means responsive to a decrease in voltage of said source for rendering ineffective a resistance in each of said circuits, and means responsive to an increase in voltage of said source for rendering effective a resistance in each of said circuits.

38. In a system of distribution, a source of voltage, a plurality of work circuits connected in shunt to said source, a plurality of resistance elements in each of said circuits and individual to said circuits, a shunt path for each of said resistances whereby each resistance may be made ineffective, and means responsive to changes in voltage of said source for holding substantially constant the current in said circuits, said means comprising automatic means for controlling the shunt paths of said resistance elements.

39. In a system of distribution, a source of voltage, a plurality of work circuits connected in shunt to said source, a plurality of resistance elements in each of said circuits and individual to said circuits, a shunt path for each of said resistances whereby each resistance may be made ineffective, means for holding substantially constant the current in said circuits, said means comprising electromagnetic means responsive to an increase in voltage of said source for opening said shunt paths, and electromagnetic means responsive to a decrease in voltage of said source for closing said shunt paths.

40. In a system of distribution, a source of voltage, a work circuit connected to said source and containing a plurality of resistance elements, a voltmeter in circuit with said source, means for changing the calibration of said voltmeter in response to variations in said source, shunt paths for said resistances, and a plurality of electromagnetic means controlled by said voltmeter for successively controlling a plurality of said shunt paths.

41. In a system of distribution, a source of voltage, a plurality of resistance elements, a work circuit containing said source and said resistance elements, a voltmeter in circuit

cuit with said source, shunt paths for said resistances, electromagnetic means responsive to the action of said voltmeter for controlling the opening of said shunt paths for an increase in voltage of said source, and electromagnetic means responsive to said voltmeter for controlling the closing of said shunt paths for a decrease in voltage of said source.

42. In a system of distribution, a source of voltage, a voltmeter, a plurality of resistance elements, shunt paths for said resistances, a circuit containing said source, said voltmeter and said resistances, electromagnetic means responsive to said voltmeter for controlling the successive opening of said shunt paths for an increase in voltage, and electromagnetic means responsive to said voltmeter for controlling the successive closing of said shunt paths for a decrease in voltage.

43. In a system of distribution, a source of voltage, a voltmeter relay, a plurality of resistance elements, a circuit containing said source, said relay and said resistances, shunt paths for said resistances, and means for changing the calibration of said relay and controlling the current in said circuit, said means comprising electromagnetic means responsive to said voltmeter for controlling the opening of said shunt paths for an increase in voltage, and electromagnetic means responsive to said voltmeter for controlling the closing of said shunt paths for a decrease in voltage.

44. In a system of distribution, a source of voltage, a resistance, a voltmeter, a work circuit containing said source, said resistance and said voltmeter, a shunt path for said resistance, means under the control of a contact of said voltmeter for closing said shunt path, and means under the control of another contact of said voltmeter for opening said shunt path.

45. In a system of distribution, a source of voltage, a voltmeter, a plurality of resistance elements, a circuit containing said source, the winding of said voltmeter and said resistances, a plurality of relays, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means under the control of said voltmeter for controlling said relays for an increase in voltage of said source, and electromagnetic means under the control of said voltmeter for controlling said relays for a decrease in voltage.

46. In a system of distribution, a source of voltage, a voltmeter, a plurality of resistance elements, a circuit containing said source, the winding of said voltmeter and said resistances, a plurality of deenergized relays, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means under the control of a contact of said voltmeter

for successively energizing said relays for an increase in voltage of said source, and electromagnetic means under the control of another contact of said voltmeter for successively deenergizing said relays for a decrease in voltage of said source.

47. In a system of distribution, a source of voltage, a voltmeter, a plurality of resistance elements, a circuit containing said source, said resistance elements and the winding of said voltmeter, a plurality of relays, means comprising one of said relays for short circuiting each of said resistances, automatic means responsive to said voltmeter for progressively operating said relays in predetermined order in one direction, and automatic means for locking each of said relays after each relay has operated.

48. In a system of distribution, a source of voltage, a voltmeter in circuit with said source, a plurality of resistance elements, a circuit containing said source, and said resistance elements, a plurality of relays, means comprising one of said relays for short circuiting each of said resistances, automatic means for progressively operating said relays in a predetermined order in one direction to compensate for changes in voltage of said source, and means for insuring the progressive reverse operation of said relays.

49. In a system of distribution, a source of voltage, a voltmeter in circuit with said source, a plurality of resistance elements, a circuit containing said source and said resistances, a plurality of relays, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means responsive to said voltmeter for controlling one of said relays, and automatic means for removing said last mentioned relay from the control of said electromagnetic means, and for placing another of said relays under the control of said electromagnetic means whereby fluctuations in the voltage of said source may be compensated.

50. In a system of distribution, a source of voltage, a voltmeter in circuit with said source, a plurality of resistance elements, a circuit containing said source and said resistances, a series of relays adapted to be operated successively in either direction, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means responsive to an increase in voltage of said source and controlled by said voltmeter for controlling one of said relays, electromagnetic means responsive to a decrease in voltage and controlled by said voltmeter for controlling that relay of said series which is immediately previous to the one under the control of the said first electromagnetic means, and means for transferring the control of both said

electromagnetic means to other relays of said series.

51. In a system of distribution, a source of voltage, a plurality of resistance elements, a circuit containing said resistance and said source of voltage, a voltmeter associated with said source of voltage, a relay for each of said resistances, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means responsive to said voltmeter, connections whereby said means normally controls one of said relays, and automatic means for removing the control of said electromagnetic means from said normally controlled relay to another of said relays, whereby the shunt paths for said resistances may be opened in a predetermined order.

52. In a system of distribution, a source of voltage, a plurality of resistance elements, a circuit containing said source and said resistances, a voltmeter connected to said source, a normally deenergized relay for each of said resistance elements, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means responsive to said voltmeter, connections whereby said means normally controls one of said relays, and means comprising a second series of relays for removing the control of said electromagnetic means from said normally controlled relay to another of said first series of relays whereby the shunt paths for said resistances may be opened in a predetermined order.

53. In a system of distribution, a source of voltage, a plurality of resistance elements, a circuit containing said source and said resistance elements, a voltmeter connected to said source, a normally deenergized relay for each of said resistance elements, a shunt path for each of said resistances comprising a movable contact of one of said relays, electromagnetic means controlled by a contact of said voltmeter, connections whereby said means controls the progressive energization of said relays for opening said shunt paths, a second electromagnetic means controlled by a second contact of said voltmeter, and connections whereby said second mentioned means controls the progressive deenergization of said relays for closing said shunt paths.

54. In a system of distribution, a source of voltage, a variable resistance, a voltmeter having a winding responsive to changes in said source, a work circuit comprising said source and said variable resistance, electromagnetic means responsive through the intermediary of said voltmeter to changes in voltage of said source for varying the calibration of said voltmeter, and for producing a proportionate variation in the value of said resistance whereby the

current in said work circuit may be held substantially constant.

55. In a system of distribution, a source of voltage, a voltmeter having a winding responsive to changes in voltage of said source, a variable resistance in circuit with the winding of said voltmeter, a second variable resistance, a work circuit comprising said source of voltage and said second variable resistance, electro-magnetic means responsive through the intermediary of said voltmeter to changes in voltage of said source for producing a proportionate variation in the value of said resistances whereby the current in said work circuit may be held substantially constant.

56. In a system of distribution, a source of voltage, a voltmeter, a plurality of resistance elements, an electric circuit comprising said source, said resistance elements and the winding of said voltmeter, a plurality of additional resistance elements, a work circuit comprising said source of voltage and said additional resistance elements, a plurality of relays, shunt paths under the control of said relays for said resistances, electromagnetic means and electrical connections for causing a plurality of said relays to open the shunt paths of a plurality of said resistance elements in said electric circuit while opening the shunt paths for a smaller number of the resistance elements in said work circuit whereby the current in said work circuit may be regulated.

57. In a system of distribution, a source of voltage, a voltmeter responsive to fluctuations in said source, a series of relays under the control of said voltmeter, means under the control of contacts of said relays for varying the calibration of said voltmeter, a plurality of work circuits, a variable resistance in each of said circuits and individual to each of said circuits, and automatic means under the control of contacts of said relays for producing equal variations in said variable resistances whereby the current in said work circuits may be regulated.

58. In a system of distribution, a source of voltage, a voltmeter responsive to fluctuations in said source, a series of relays under the control of said voltmeter, means under the control of contacts of said relays for varying the calibration of said voltmeter, a plurality of work circuits, a plurality of resistance elements in each of said circuits and individual to each of said circuits, a shunt path for each of said resistance elements, electromagnetic means for controlling said shunt paths and connections whereby said electromagnetic means are controlled by contacts of said relays.

59. In a system of distribution, a source of voltage, a voltmeter responsive to fluctuations in said source, a series of normally

deenergized relays, electromagnetic means under the control of said voltmeter for energizing said relays, electromagnetic means under the control of said voltmeter for deenergizing said relays, means under the control of contacts of said relays for varying the calibration of said voltmeter, a plurality of work circuits, a plurality of resistance elements in each of said circuits, shunt paths for said resistances, means comprising a set of relays for controlling the shunt paths of the resistances of a plurality of said work circuits, means comprising a second set of relays for controlling the shunt paths of the resistances of another of said work circuits, and circuit connections for placing said sets of relays under the control of said series of relays whereby the current in said work circuits may be held substantially constant.

60. In a system of distribution, a source of electrical energy, a plurality of circuits connected thereto and including variable resistances, a voltmeter included in one of said circuits, a plurality of relays controlled by the action of said voltmeter, and means under the control of said relays for varying said resistances.

61. In a system of distribution, a source of electrical energy, a circuit connected thereto including a plurality of resistance elements, shunt paths about said resistance elements, a voltmeter, another circuit connected to said source including the winding of said voltmeter and a plurality of resistance elements, short circuits about said second mentioned resistances, a series of relays operated by said voltmeter in response to a variation in the voltage at said source, and means under the control of said relays for opening or closing said short circuits and said shunts.

62. A regulator comprising a solenoid, an element controlled thereby, and means for automatically changing the calibration of said solenoid an amount dependent upon the intensity of the energizing force supplied to said solenoid and comprising imped-

ance elements, movable contacts individual to said elements, and solenoids individual to said contacts.

63. A regulator comprising a solenoid, a plurality of relays controlled thereby, means whereby one of said relays operates for an increase in the energization of said solenoid, another of said relays operating for a decrease in the energization of said solenoid, an impedance in circuit with said solenoid and controlled by said solenoid, and a regulating element controlled by said relays.

64. In a system of distribution, a source of electrical energy, a plurality of circuits connected thereto and including variable resistances, a voltmeter included in one of said circuits, a solenoid controlled by the action of said voltmeter, and means under the control of said solenoid for varying said resistances.

65. In a system of distribution, a source of electrical energy, a voltmeter connected to said source, a series of relays, means controlled by the action of said voltmeter for operating successively the relays included in said series, a plurality of normally energized relays controlled by said series of relays, a conductor including a variable resistance leading from said source to a work circuit, and means controlled by said normally energized relays for varying said resistance.

66. In a system of distribution, a source of electrical energy, a plurality of circuits connected thereto, variable resistance elements associated with each of said circuits, a series of relays associated with each of said circuits and controlling the variable resistance elements associated therewith, means controlled by a variation in the voltage at said source for controlling one of said series of relays, and means controlled by said last mentioned series of relays for controlling another of said series of relays.

In witness whereof, I hereunto subscribe my name this 21st day of July, A. D., 1919.

ROY D. CONWAY.