

Aug. 22, 1944.

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2,356,269

VOLTAGE REGULATED RECTIFYING SYSTEM

Filed Sept. 4, 1942

2 Sheets-Sheet 1

FIG. 1

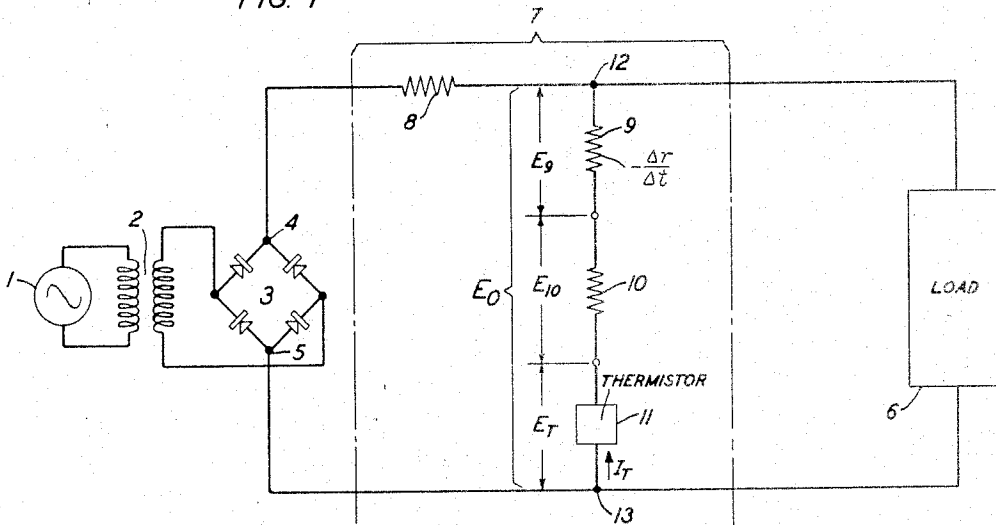
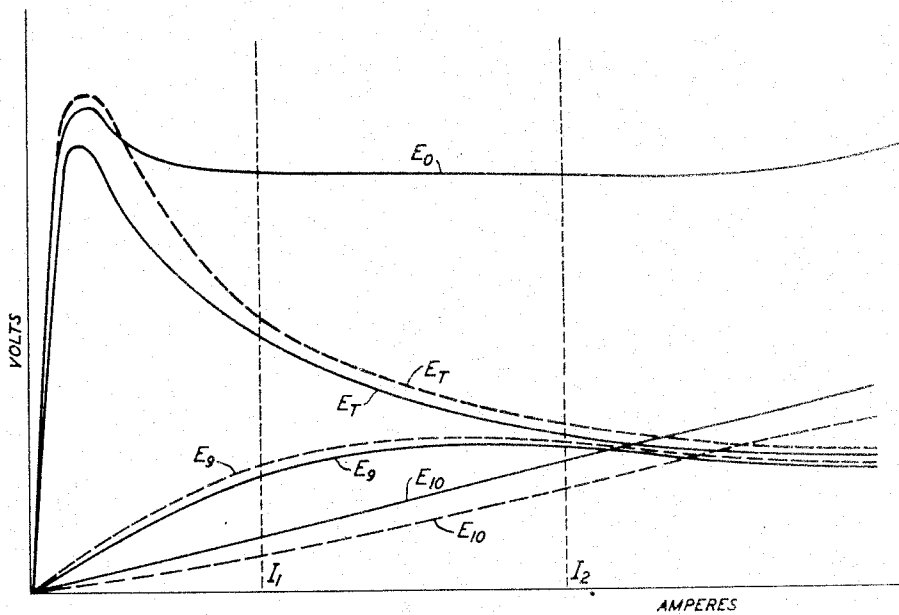


FIG. 2



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2 Sheets-Sheet 2

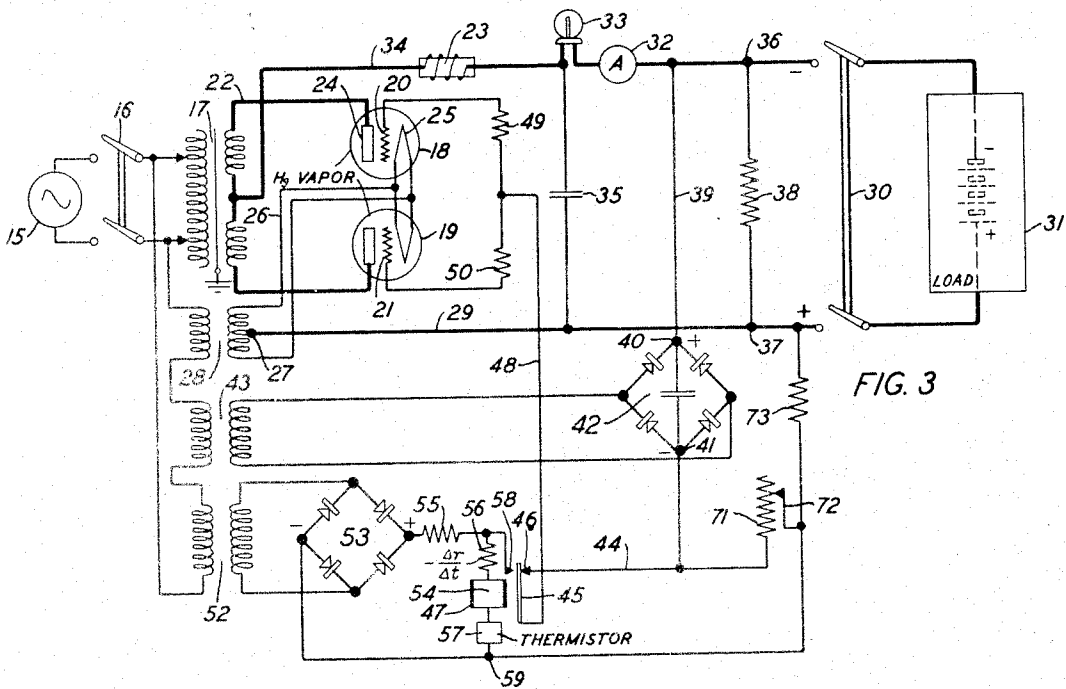


FIG. 3

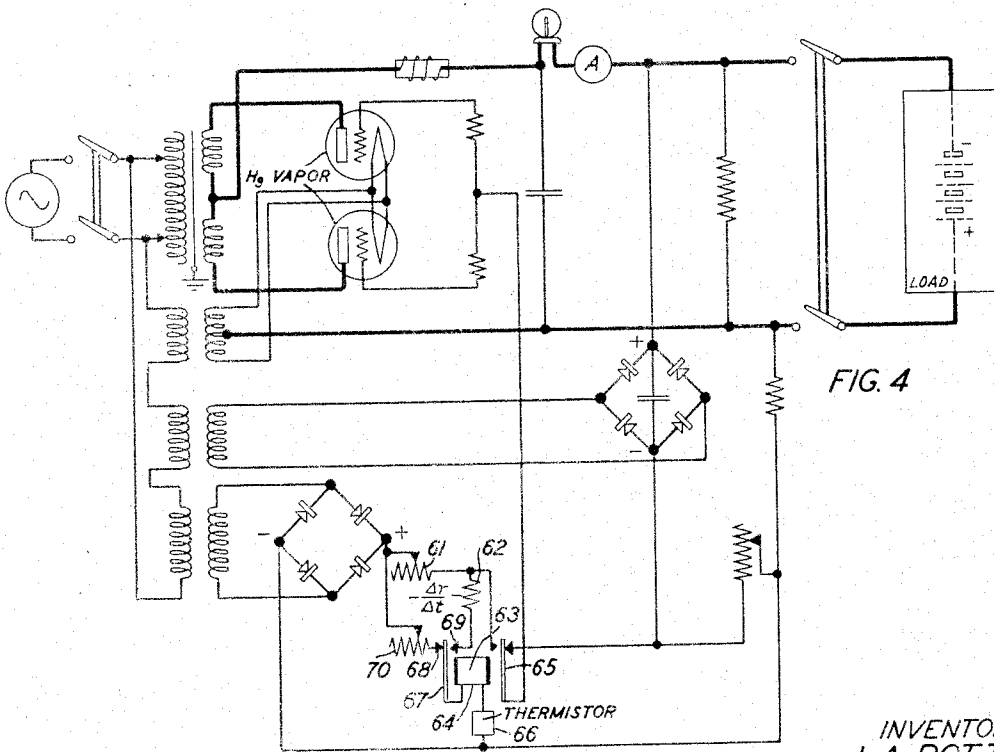


FIG. 4

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2,356,269

VOLTAGE REGULATED RECTIFYING
SYSTEM

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Application September 4, 1942, Serial No. 457,258

10 Claims. (Cl. 175—363)

This invention relates to regulated rectifying systems for converting alternating current to unidirectional current.

One object of the invention is to provide a suitable source of biasing electromotive force for electron discharge devices used for alternating current rectification.

Another object of the invention is to provide a regulating rectifying system which will produce a substantially constant electromotive force irrespective of changes in the ambient temperature.

A further object of the invention is to provide a regulated rectifier in which the regulating function may be combined with a time delay function in order to simplify the essential apparatus.

An additional object of the invention is to provide a regulated rectifying system which will automatically delay effective application of space current electromotive force to a thermionic rectifier until the cathode of the rectifier shall have become sufficiently heated to avoid injury to the rectifier.

In accordance with the invention the unidirectional electromotive force which a varying voltage alternating current source impresses through a rectifier upon a load is maintained substantially constant by a series resistor, the potential drop across which is controlled by the variable current traversing a shunt path connected across the load terminals and hence also traversing the series resistor. The shunt path includes in series connection a resistance element having a negative temperature coefficient of resistance, a resistance element having a positive temperature coefficient of resistance and a thermistor, the resistance of which falls very rapidly with increasing current therethrough. If the electromotive force of the rectified current impressed across the load and across the shunt path should tend to rise the current through the shunt path would increase enormously on account of the decrease of resistance of the thermistor. The current through the series resistor and the potential drop thereacross would likewise increase, thus reducing the net electromotive force available across the load terminals.

If the regulated unidirectional electromotive force is to be utilized as a grid bias potential for a thermionic rectifying system, that resistance element of the shunt control path which exhibits a positive temperature coefficient of resistance may be the winding of an electromagnetic relay of a marginal type. Upon initial application of the alternating electromotive force to the rectifying system the thermistor in the control path will

present an extremely high resistance. Consequently, the energization of the marginal relay will be delayed until the thermistor has heated to such a degree as to permit a current of sufficient magnitude to actuate the relay to traverse a shunt path. Below the relay is actuated the circuit provides a negative voltage at the grids of the thermionic rectifiers sufficient to prevent the space current from flowing. When the relay actuates its armature it applies a reduced grid voltage in accordance with the regulating characteristics of the system so that space current flows in the thermionic rectifier at a time when the cathode of the thermionic rectifier has become sufficiently heated so that application of the space current may safely be made.

Additional objects and aspects of the invention will be apparent upon consideration of the following specification taken in connection with the accompanying drawings in which:

Fig. 1 is a schematic diagram of a regulated rectifying system embodying certain principles of the invention;

Fig. 2 is a graph of the voltage current characteristics of certain elements of the circuit of Fig. 1;

Fig. 3 presents a circuit diagram of a rectifying system designed to have automatic output voltage regulation; and

Fig. 4 shows a modification of the rectifying system of Fig. 3.

Referring to Fig. 1 there is shown a source 1 of alternating current connected by a transformer 2 to the input terminals of a full wave rectifier 3 to the output terminals 4 and 5 of which a load 6 is connected through an L regulating network 7. The regulating network comprises a series resistor 8 which reduces the unidirectional electromotive force available at the input terminals of the load 6 by the amount of the potential drop occurring in resistor 8. The regulating network also includes a shunt arm comprising resistor 9, resistor 10 and thermistor 11 connected in series. The resistor 8 may be of a type in which the resistance remains substantially constant with temperature and with load or it may have a positive temperature coefficient of resistance so that the potential drop across the resistor increases with increased temperature and increases with increased load somewhat more rapidly than does the load. Resistor 9 preferably consists of a material such as carbon which possesses a negative temperature coefficient of resistivity. Accordingly, with increase in temperature of the resistor 9, its resistivity falls. Resistor 10 prefer-

ably comprises a substance such as copper having a positive temperature coefficient of resistivity. Resistor 10 is preferably wound on a spool or mandrel which is not a heat insulator but provides a heat conduction path from the resistance wire to the ambient air so that the wire will readily change its temperature in response to ambient temperature changes. For the same reason the protective finish applied to the wire should also be a good heat conductor. Accordingly, since heat may readily pass to the atmosphere the temperature rise in the wire occasioned by flow of current therethrough will be minimized. However the wire will be quite subject to ambient temperature changes and its changing resistance will accordingly compensate over a wide range for the effects of ambient temperature changes upon other elements of the rectifying system. The thermistor 11 is preferably of a well-known type in which the resistance drop thereacross increases steeply with current from a cold condition of zero current or no load until a certain temperature is attained after which the resistance of the thermistor and consequently the potential difference between its terminals falls rapidly with increased current therethrough.

It will be apparent that the source 1 will supply alternating current to the rectifier 3 which will deliver rectified unidirectional current from its output terminals 4, 5 to the load 6. Across the input terminals 12 and 13 of the load circuit an electromotive force E_o will be delivered. Assume that under any given set of conditions the resistances of elements 9, 10 and 11 are such as to cause the shunt path including these elements to receive a current I_r . The corresponding electromotive force or potential difference across the terminals of thermistor 11 may be designated by E_r . In Fig. 2, the solid line graph labeled E_r illustrates the relation between the electromotive force developed across and the current through the thermistor 11. The corresponding potential drop across resistor 10 is indicated by the solid line graph E_{10} . The potential drop across resistor 9 is indicated by graph E_9 which is curved because of the fact that the resistivity of element 9 decreases with increase in temperature. The resistivity of resistor 9 accordingly decreases with increase of current I_r through the shunt path including resistor 9. As indicated the resistivity begins to fall off more rapidly than the current increases so that the potential E_9 reaches a maximum and slowly declines. The sum of the electromotive forces E_r , E_9 and E_{10} is indicated by the graph E_o . Throughout the range of values of the current I_r extending from the magnitude I_1 to I_2 , the output voltage E_o is substantially constant. This comes about because of the fact that the combined upward slope of the graphs E_9 and E_{10} is about equal to the downward slope of the graph E_r . Moreover, the downward curvature of graph E_r is substantially compensated for by the upward curvature of the graph E_9 . The system may, therefore, be designed to operate over the range of shunt current I_r extending from I_1 to I_2 with extremely small variation of the output voltage E_o .

Regulation is effected by increase or decrease of the shunt current I_r and corresponding increase or decrease of the potential drop occurring across the series resistor 8. If apparatus of this general type is employed for constant voltage small current loads, the series current traversing resistor 8 will have a magnitude substantially equal to the shunt current I_r and the potential

drop across the resistor 8 will accordingly depend chiefly upon the magnitude of the current I_r .

As preferably designed the output electromotive force E_o will slightly increase as the shunt current varies from I_1 to I_2 . It may considerably increase if the resistance of element 10 which has a positive temperature coefficient be made high. On the other hand, it may even be made to decrease if the resistance of the element 10 is made low.

The solid line graphs of Fig. 2 which have been discussed are those presenting the operational characteristics under conditions of warm ambient temperature. The broken line graphs which are similarly labeled present the corresponding operational characteristics under conditions of cool ambient temperature. It will be apparent that under the cooler condition the resistance of the thermistor element 11 and the potential drop thereacross for a given current I_r will be higher. Under the same conditions the resistance, and, consequently, the potential drop across element 9 will, likewise, increase. However, the resistance and potential drop across the element 10 will diminish and to about such an extent as to compensate for the changes occurring in the other two resistors. It follows, that E_o will be maintained at substantially the same magnitude as before.

Assuming that the magnitude of resistance 10 has been made such that the output voltage E_o will remain substantially constant, but with a slightly rising magnitude as the shunt current varies from I_1 to I_2 , it will be apparent that in operation any condition which tends to cause the load potential across points 12, 13 to slightly increase will be attended with a relatively large increase in the shunt current I_r . In consequence, the series current flowing through resistor 8 and the potential drop across the resistor will very rapidly increase thus tending to reduce the resultant electromotive force across points 12, 13. Accordingly, the circuit as disclosed is very effective in regulating the load potential under conditions of varying input voltage at the terminals 4, 5 or for any other reason which may tend to change the potentials across the points 12, 13. Moreover, the regulated voltage remains substantially unaffected by change in ambient temperature since the resistance temperature characteristics of the regulating elements are to a large extent mutually compensating.

Fig. 3 discloses a thermionic rectifying system of the general type illustrated in United States Patent 2,155,515, April 25, 1939, to D. E. Trucksess. This type of rectifier uses three-element grid control mercury vapor tubes. In this circuit a source 15 of alternating current is connected through a switch 16 and a current supply transformer 17 to a full wave thermionic rectifier comprising the mercury vapor filled electronic devices 18 and 19 provided with impedance control elements 20 and 21 respectively. The path of the rectified current may be traced from the upper terminal 22 of the secondary winding of the current transformer 17 by way of anode 24, cathode 25 of the discharge device 18, the common cathode current supply path 26 to the mid-tap 27 of the secondary winding of the cathode heating current transformer 28, thence over the main conductor 29 to lower armature and contact of switch 30 to the load 31 and return through the upper contact and armature of switch 30, ammeter 32, ballast lamp 33, smoothing choke

coil 23 and main conductor 34 to the mid-tap of the secondary winding of transformer 17. Shunt capacitor 35 assists in smoothing the rectified current in a well-known manner. Impedance control elements 20 and 21 are electrically biased to a potential determined by introduction into the biasing path of an electromotive force derived from the load input terminals and a constant reference electromotive force, the source of which will presently be described. The load input potential which, in the operation of the device is delivered across points 36 and 37, is impressed across the resistor 38. A grid biasing electromotive force tending to render the grids negative with respect to their cathodes is produced across terminals 40 and 41 of the full wave rectifier 42 which is supplied with alternating current from the auxiliary transformer 43. Lead 39 connects the terminal 40 of rectifier 42 directly to the negative terminal 36 of the load supply circuit. Resistor 71 having a variable tap connection 72 and resistor 73 connect the terminal 41 of rectifier 42 to the positive terminal 37 of the load supply circuit. The rectifying elements of the rectifier 42 are so poled as to render terminal 41 of the rectifier negative with reference to terminal 40. The potential of lead 44 will therefore be negative with reference to that of terminal 37 and the cathodes. Since the rectified potential between terminals 40 and 41 is a function of the voltage of the supply circuit and varies therewith the resulting potential between the cathodes and the grids which is effective across resistor 73 and resistor 71 will be reasonably constant. It should have such a magnitude at no load as to maintain the impedance of the tubes 19 and 20 sufficiently high to substantially block current therethrough. A biasing circuit may therefore be traced from the cathode 25 over the supply lead 26, point 27, conductor 29, the positive terminal 37 of resistor 38 through the resistor and conductor 39 to point 40, across the output of the rectifier 42 to point 41, conductor 44, armature 45 and right-hand contact 46 of relay 47, conductor 48 thence in parallel through resistances 49 and 50 to the respective grids 20 and 21. The resultant or net biasing potential will render the grids 20 and 21 so negative as to substantially preclude passage of current through the electron discharge devices 18 and 19.

Another auxiliary transformer 52 supplies an alternating electromotive force to a full wave rectifier 53, preferably of the copper oxide type, to the output terminals of which is connected an L type network serving as a voltage regulator and substantially identical in its characteristics with the regulating network 7 of Fig. 1 except that the resistance 10 with the positive temperature coefficient has been replaced by a winding 54 of relay 47. The series resistor 55, the shunt resistor 56 and the thermistor 57 correspond respectively to elements 8, 9 and 11 of Fig. 1. It will therefore be understood that a substantially constant unidirectional electromotive force will be delivered between the left-hand contact 58 of the relay 47 and the lower terminal 59 of thermistor 57.

As shown in Fig. 3, the circuit is in idle condition with switches 16 and 30 open. When, in starting the operation of the rectifying system switches 16 and 30 are closed, the rectifying devices 18 and 19 will pass substantially no current since, as has been explained, the potentials of grids 20 and 21 are highly negative with reference to their associated cathodes. During the time that the cathodes are coming up to normal

operating temperature transformer 52 is applying an electromotive force to the shunt path 56, 54, 57. The magnitude of the current in this shunt path is at first very small because of the high resistance of the cold thermistor 57. The thermistor takes an appreciable time to heat, this time being determined by the thermal characteristics of the thermistor and the medium in which it is placed. During that time the cathodes of the rectifiers 18 and 19 attain normal temperature but the thermionic rectifiers permit substantially no current to pass. When, finally, the current through thermistor 57 has increased to a magnitude sufficient to cause relay 47 to energize and pull up its armature 45, the grid biasing circuit for the electronic devices 18 and 19 is interrupted as the armature 45 moves out of engagement with contact 46. Immediately thereafter, however, the armature 45 engages contact 58 reestablishing a biasing circuit from the point 37 through resistor 73, thermistor 57, relay winding 54, negative temperature coefficient resistance 56, contact 58 and armature 45. In an actual example assume that the rectified electromotive force across points 40, 41 is about 8 volts. This electromotive force serves as the only source of negative grid potential for tubes 18 and 19 during starting in case the switch 30 is left open or the battery is otherwise disconnected. In this event there is no rectified voltage impressed by rectifier tubes 18 and 19 across resistor 38 since these rectifier tubes are prevented from passing current during the starting period. As soon as the relay 47 operates to introduce the rectified potential between points 58 and 59 current begins to flow through resistor 38. If the potential across resistor 38 be about 48 volts the total electromotive force between points 37 and 41 will be about 56 volts. The potentiometer point 72 may be so set as to derive some 93 per cent of this voltage or 52 volts for the grid bias. Opposed to this bias potential of 52 volts negative is the positive potential across 58, 59 which may be about 49.5 volts. The resultant is a negative 2.5 volt grid bias potential on grids 20 and 21 which permits normal load current to pass to the load 31 when switch 30 is closed. During operation the net grid bias may range from 1 to 3 volts negative with reference to the cathodes.

It will be seen therefore that during the initial stage of starting thermistor 57 while heating serves with relay 47 to effect a time delay operation. After the rectifying system has been placed fully in operation the thermistor 57 serves, together with the winding 54 of relay 47 and other elements of the L network, to provide a closely regulated constant reference potential opposed to the regulated potential of the rectifier output circuit in order to supply the proper impedance control electromotive force to the grids of the rectifying devices. The time delay attained by the thermistor also enables the thermistor to become sufficiently heated so that when it is called upon to serve in the voltage regulator circuit it has already reached a point on its voltage current characteristic within or near its operating range.

It has been explained that the L network co-operating with full wave rectifier 53 serves to provide a closely regulated unidirectional electromotive force which may serve as a reference potential in lieu of a battery or other primary source. In the operation of the rectifier system of Fig. 3 as a whole, the impedances of devices 18 and 19 and the current which they pass de-

depends upon the net biasing potential applied to grids 20 and 21. This biasing potential is determined by two series electromotive forces operating in the grid biasing path from the cathodes to the grids. One of these is the potential effective between points 37 and 72 and tending to render the grids negative. This potential is proportional to the regulated load potential and the rectified auxiliary potential supplied by auxiliary rectifier 42, which are connected in series aiding. The other series electromotive force is the constant reference potential introduced between terminal 59 and contact 58 and which opposes the combined load and rectified auxiliary potentials. The constant reference potential is of sufficient magnitude to reduce the net negative grid bias potential to a point at which current may flow through tubes 18 and 19.

It will be apparent that as the load potential across points 36 and 37 tends to rise the net negative grid bias potential will become greater thus reducing the current passed by tubes 18 and 19. Conversely a tendency of the load potential to fall will have a converse compensating effect.

The circuit of Fig. 4 is similar to that of Fig. 3, the principal difference residing in the L network which supplies substantially constant unidirectional reference potential for the grid biasing path of the thermionic rectifier. It was explained in connection with the disclosure of Fig. 1 that the optimum relationship for maintaining the output electromotive force of the L network substantially constant depends upon the relative magnitudes of the resistances of the thermistor and the two resistors in series therewith in the shunt path. In the circuit of Fig. 4, the series resistor 61 and the shunt resistor 62 may have temperature coefficients of resistivity which are respectively positive and negative and the winding 63 of relay 64 may be designed to have optimum characteristics for regulation. However, it will be recalled that the time delay provided by the relay 64 depends upon the time for current therethrough to rise to the marginal magnitude at which the relay will pull up its armature 65 to transfer the grid bias circuit from a no load grid polarization to an operating load grid polarization. The time for the current to rise to this value in turn depends upon the thermistor 66 and the other resistances in series with thermistor 66 and the relay winding 63 at the time that an energizing electromotive force is first applied. It is, therefore, desirable to be able to separate the two functions of voltage regulation and time delay to such an extent as to be able to variably adjust either without deleteriously affecting the other. This is accomplished in the circuit of Fig. 4 by providing relay 64 with an additional armature 67 and contacts 68 and 69. In the idle condition of the apparatus, armature 67 is in engagement with contact element 68, thus connecting the thermistor and relay winding in series with a resistor 70 which may be designed to have the proper magnitude to enable thermistor 66 and relay 64 operating in conjunction to give the proper time delay. Until relay 64 operates there is no voltage regulating action and none is necessary since the L network is not connected in the grid bias circuit. As soon, however, as the relay 64 operates to attract its armature thus determining the time delay the movement of armature 67 into engagement with contact 69 transfers the thermistor and the relay to the shunt regulating path. Thereafter, so long as power is supplied the

apparatus functions in the same manner as that of Fig. 3.

What is claimed is:

1. An L network for regulating voltage to be applied from a source to a load comprising a series resistor arm having two terminals to be connected respectively to the source and one terminal of the load and a shunt arm having one terminal connected to the load terminal of the series arm and having a second terminal for connection to the other load terminal, said shunt arm including in series a resistor element the resistance of which is very high when the element is cold but which falls rapidly with increase in temperature of the element and a resistance element having a negative temperature coefficient of resistance.

2. An L network for regulating voltage to be applied from a source to a load comprising a series resistor arm having two terminals to be connected respectively to the source and one terminal of the load and a shunt arm having one terminal connected to the load terminal of the series arm and having a second terminal for connection to the other load terminal, said shunt arm including in series a resistor element the resistance of which is very high when the element is cold but which falls rapidly with increase in temperature of the element, a resistance element having a positive temperature coefficient of resistance and a resistance element having a negative temperature coefficient of resistance.

3. An L network for regulating voltage to be applied from a source to a load comprising a series resistor arm having two terminals to be connected respectively to the source and one terminal of the load and a shunt arm having one terminal connected to the load terminal of the series arm and having a second terminal for connection to the other load terminal, said shunt arm including in series a resistor having a positive temperature coefficient of resistance and a resistor having a negative temperature coefficient of resistance.

4. A regulating system comprising a source of current of varying electromotive force, a load to be connected thereto and a regulating section electrically connecting the terminals of the source to the terminals of the load, said section comprising a series arm having an effective resistance and a shunt arm including in series a resistor element the resistance of which is very high when the element is cold but which falls rapidly with increase in temperature of the element, a resistor having a positive temperature coefficient of resistance and a second resistor having a negative temperature coefficient of resistance, the three elements of the shunt arm having such current for the characteristics that over a relatively wide range of magnitudes of current therethrough the total series electromotive force across the shunt branch may be substantially constant.

5. A regulating network comprising two input terminals for connection to a source of alternating current, two output terminals for connection to a load, a series resistance element connected between one input terminal and one output terminal, two resistors, one of which has one terminal connected to the input terminal of the series resistance element and the second terminal connected to a stationary contact point, the other resistor of which has one terminal connected to the output terminal of the series resistance ele-

ment and a second terminal connected to a second stationary contact point and a shunt path having one end connected to the input terminal and the output terminal remote from the series resistance element, the shunt path including in series arrangement a thermistor, the winding of an electromagnetic relay and the armature of the electromagnetic relay, said armature being positioned to make contact alternately with the two stationary contact points.

6. A rectifying system comprising a rectifier, input terminals connected thereto for impressing an alternating electromotive force thereupon, output terminals connected thereto for deriving unidirectional current energy therefrom, said rectifier comprising an electron discharge device having a cathode, an anode and a control electrode, a biasing circuit including a source of blocking electromotive force connected between the cathode and the control element to prevent operation of the rectifier when its elements are cold, a path including the winding of an electromagnetic relay and a resistor element, the resistance of which is very high when the element is cold but which falls rapidly with increase in temperature of the element in series therewith connected to said input terminals, the relay having an armature connected to the control element and a contact normally engaged by the armature, the armature and contact being in series in the blocking biasing circuit, a second contact for the relay in position to be engaged by said armature when the relay is energized and a connection from said second contact to a point of positive potential of said path whereby when a predetermined time has elapsed after application of the alternating current electromotive force to the input terminals the resistor permits the relay to energize to disconnect the source of blocking electromotive force and to connect the control element to the point of positive potential to enable the rectifier to function.

7. A regulated energy transfer circuit including a pair of input terminals, an impedance control bias path connected to said terminals to be energized therefrom, a pair of output terminals, a second impedance control bias path connected to said output terminals to be energized therefrom, an energy transmission path connecting the input terminals to the output terminals and including in series the space path of an electronic device having a cathode, an anode and an impedance control element, an electromagnetic relay having a winding connected in series in the first bias path with a falling resistance temperature characteristic resistor, two contacts of the relay electrically connected one to the first bias path and the other to the second, and an armature adapted to alternately engage the contacts positioned to be controlled by the flux through said winding and connected to the impedance control element whereby upon application of an input electromotive force to the input terminals the relay winding becomes energized after a time determined by the heating of the falling tem-

perature characteristic resistor and actuates the armature to transfer the effective control element bias potential from one bias circuit to the other.

8. A rectifying system comprising a rectifier having a pair of input terminals to which an alternating current supply system may be connected, a pair of output terminals and an L network connected between the rectifier and its output terminals for regulating the voltage to be supplied to the output terminals, said network comprising a series resistor electrically connected between the rectifier and one output terminal, an electrical conductor connected between the rectifier and the other output terminal, a regulating path extending from the conductor in series through a resistor element, the resistance of which is very high when the element is cold but which falls rapidly with increase in temperature, the winding of an electromagnetic relay and the armature of the relay, alternate contacts which the relay is adapted to respectively engage when the relay is deenergized or energized, one of said contacts being connected by a resistance path to the junction point of the rectifier and the series resistor and the other of the contacts being connected by a separate resistance path to the junction of the series resistor and the output terminal.

9. A regulating network comprising a series resistor having an input terminal to be connected to a source and an output terminal to be connected to a load, a shunt arm having one terminal connected to a second input terminal and a second output terminal and also having a negative current voltage characteristic whereby current through the shunt arm increases more rapidly than the terminal electromotive force applied to the arm, connecting means in said shunt arm initially connecting the shunt arm to the input terminal of the series resistor, said connecting means being responsive to shunt arm current in excess of a predetermined magnitude to shift the connection of the shunt arm from the input terminal of the series resistor to the output terminal thereof.

10. A current supply system having a pair of input current terminals; a path connected to said terminals to be energized therefrom and including, in series, a resistor, the resistance of which is extremely high when the resistor is cold but which falls rapidly when the resistor is heated, a relay winding, an armature for said winding, a contact with which said armature normally engages and a resistor; a second contact adjacent the armature and with which it is adapted to engage in its alternate position; a pair of output terminals; a series resistor interposed in the connection between one of the input terminals and the corresponding output terminal; a resistance path connecting the second contact to the junction of the series resistor and the output terminal and a conductive path connecting the other output terminal to the corresponding input terminal.

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