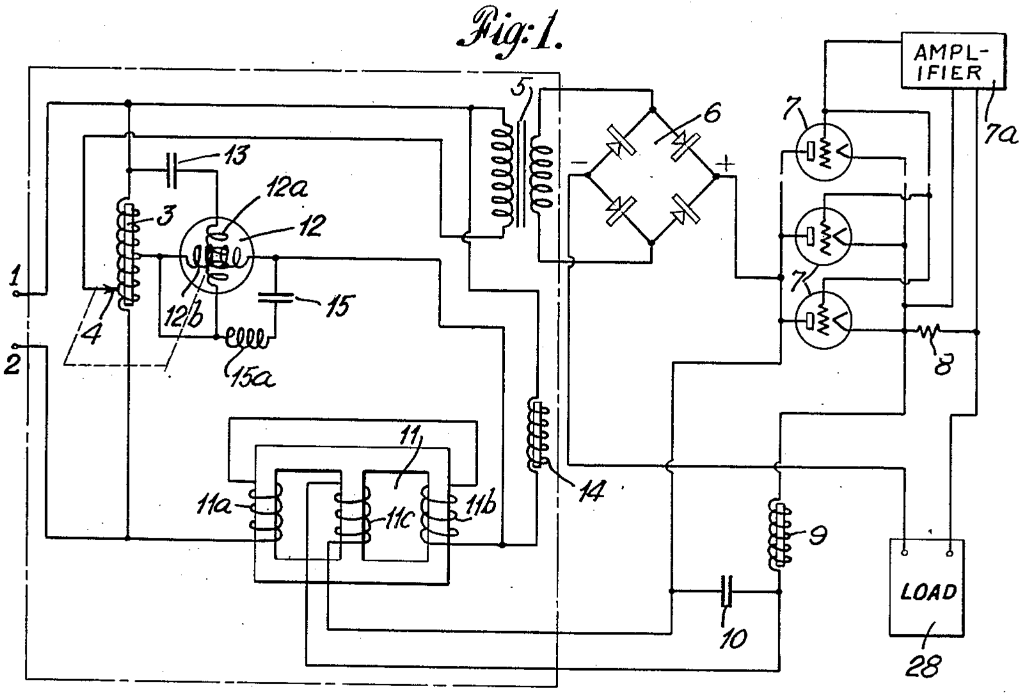
Dec. 4, 1951 J. A. POTTER 2,577,151

REGULATED RECTIFYING APPARATUS

Filed Oct. 11, 1949 2 SHEETS—SHEET 1

Fig:1.



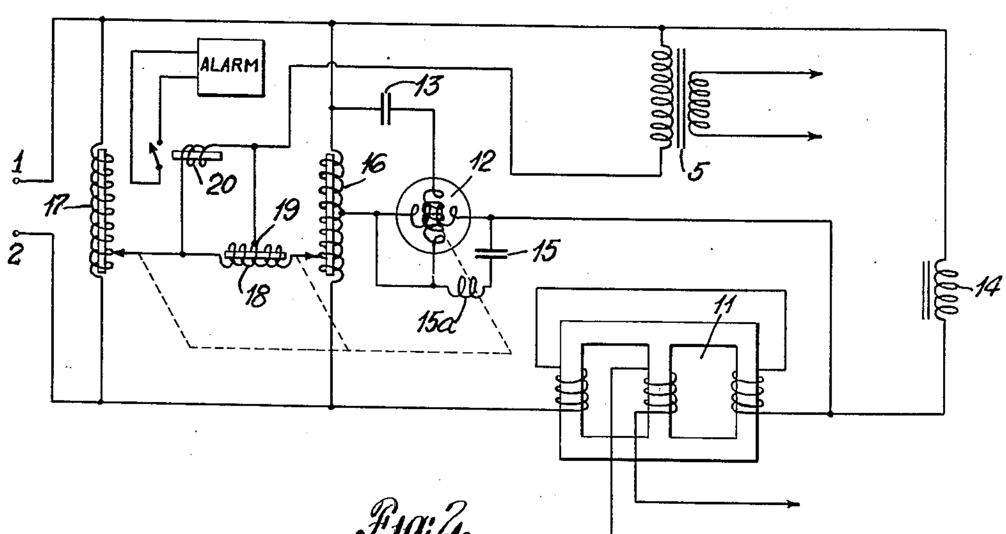


Fig:2.

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2 SHEETS—SHEET 2

Fig: 3.

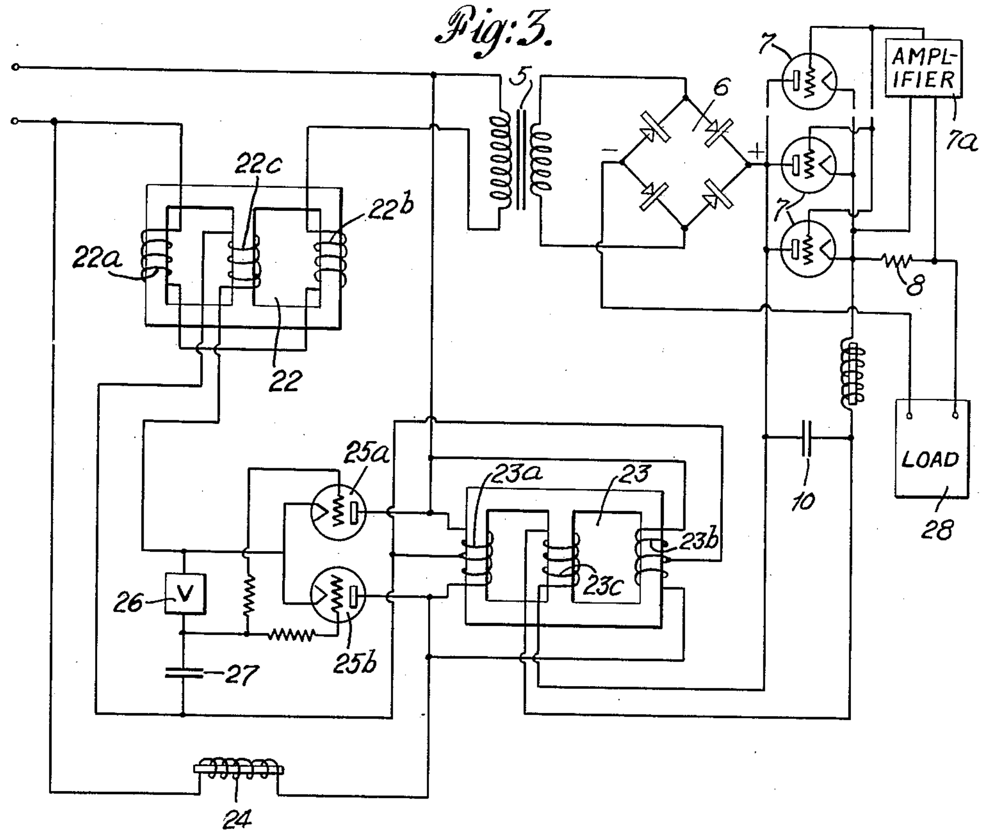
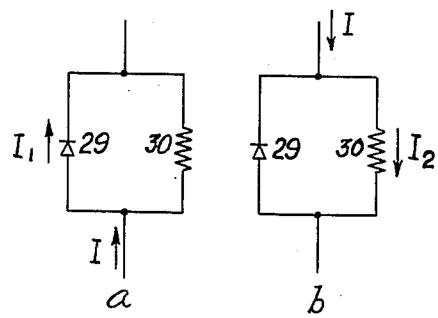


Fig: 4.



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REGULATED RECTIFYING APPARATUS

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12 Claims. (Cl. 321—25)

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The present invention relates generally to power supply systems, and more particularly, to regulated direct current power supplies providing constant current output.

In communication systems, a source of direct current is often required and is commonly produced by rectification of an available alternating current source. Such rectifiers may utilize, for example, thermionic discharge tubes or metallic disc rectifiers employing semiconductive materials such as selenium or copper oxide.

In addition, direct current power supply systems are often required to have certain regulating characteristics. By regulating characteristic is meant a control of one or more of the output parameters as the operation of rectifier is varied. For example, in the instance of supplying direct current power to repeater stations remotely located along a communication cable, a constant current output is found desirable. Constant current power supplies have also been found advantageous in the operation of submarine or underwater cable equipment.

In summary, the system employs a rectifier, rectifying current from an alternating supply source. The rectified current is supplied to the load through the space current path of a space current device, the resistance of the space current path being controlled by the load. A circuit is provided including a saturable reactor for controlling the alternating voltage impressed upon the rectifier; the saturable reactor has a saturating winding coupled across the space charge path of the space current device. The object of the invention is to provide a regulated direct current power supply having a substantially constant current output with varying conditions of the load circuit; and to provide means to protect such a constant current power supply against failure of certain of the operating elements.

The invention is described in detail in the following specification.

The invention will be explained with reference to the accompanying drawings, of which:

Fig. 1 shows a schematic diagram of a circuit in accordance with a preferred embodiment of the invention;

Fig. 2 shows schematically a modification of that portion of the circuit shown in the dotted enclosure of Fig. 1;

Fig. 3 shows a further embodiment of a circuit, according to the invention; and

Fig. 4 is an explanatory circuit diagram of a portion of the circuit according to the invention.

Referring now to the drawings, particularly Fig. 1: a source of alternating current is supplied to terminals 1 and 2. This alternating current source is then applied to an autotransformer 3 having a center tap and a sliding or variable tap 4. The variable tap 4 provides a varying voltage between itself and the end terminals of the autotransformer. The alternating current supply, as modified in voltage by the autotransformer, is then supplied from terminal 1 and the variable tap 4 to a conventional rectifier system.

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In the circuit depicted by way of illustration, the rectifier system is composed of a transformer 5 and a bridge rectifier 6. Transformer 5 is necessary to supply the proper rectifier output voltage for given alternating current supply line voltages, and to insulate the alternating supply from the direct current output. Transformer 5, however, may be dispensed with without affecting the operation of the invention. The rectifier 6 may conveniently be of the metallic disc type. Such metallic disc rectifiers ordinarily employ a semiconductive substances as copper oxide or selenium. It will be obvious to those skilled in the art that these rectifiers may also be comprised of vacuum tubes such as thermionic discharge tubes or gaseous discharge tubes.

One of the output vertices of rectifier 6 is coupled to a load circuit 28, in series with a bank of space current devices and a fixed resistance 8. These space current devices may be thermionic discharge of vacuum tubes, and will be called series regulator tubes. Such series regulator tubes 7 are represented in Fig. 1 as being triodes having each a cathode, grid and anode. The series regulator tubes 7 are interconnected in parallel; an appropriate current carrying capacity may be provided by varying their number. In addition, by the use of paralleled tubes, the failure of one tube will not disable the system. The anodes and cathodes of the series regulator tubes 7 must be connected in series with the output vertices of bridge rectifier 6 in such a manner that a positive polarity is applied at the anode of the series regulator tubes, relative to their cathodes.

Resistance to the passage of load current is developed by the insertion of the series regulator tubes 7; the magnitude of this resistance depends upon the voltage applied to the grids of tubes 7. The current drawn by the load causes a small voltage drop to appear across reistance 8. This voltage drop will be unidirectional, although varying in an amount depending upon the load current drawn. The voltage drop is applied to the grid-cathode circuit of the discharge tubes 7 through a direct coupled amplifier 7–*a*. Amplification of the voltage drop across resistance 8 increases the response of the series regulator tubes 7. The use of a thermionic discharge tube as a series regulation device is familiar, for example, as shown in United States Patent 2,075,966 to A. W. Vance, issued April 6, 1937.

The apparent resistance introduced by the series regulator tubes 7 in series with the output of the rectifier has been shown to depend upon the load current drawn. For example, an increasing load current will be amplified and will place an increased negative voltage upon the control grids of each of the discharge tubes 7. This increased negative bias voltage will increase the apparent resistance introduced by the space current path of the regulator tubes 7, and thus tends to reduce the load current to more nearly the desired value. Similarly, a decreasing negative voltage resulting from a decreasing load current will decrease the resistance of the space current path.

It is the output current of the rectifier to which constant current regulation is to be applied. The control of current will be found satisfactory over the operating limits of the regulator tubes 7 and their associated direct current amplifier 7–*a*. As operating limits of tubes 7 and amplifier 7–*a* are approached, the regulation of load current to a constant value becomes less exact; the change of grid voltage on regulator tubes 7 fails to provide sufficient variation in the resistance of the space current path to provide constant current output.

The general plan will be to vary the alternating current input voltage to the rectifier 6 in accordance with the voltage drop experienced across the regulator tubes 7. By varying the alternating current input voltage an appropriate amount, the output voltage of the rectifier, in turn, may be changed to compensate for load current changes; the load variations for which compensation may be achieved will not longer depend upon the operating range of the regulator tubes 7 and amplifier 7–*a*.

According to the invention, the voltage drop appearing between the cathodes and anodes of the regulator tubes 7 is applied through a filter comprising a choke 9 and a capacitance 10, to the control winding of a saturable reactor 11. Thus, as the regulator tubes 7 operate over the control range as has been described, a correspondingly varying voltage drop will appear through the filter composed of elements 9 and 10 to the control winding of saturable reactor 11.

The system to control the alternating current input voltage supplied to the rectifier may now be described. The relative position of the previously described variable tap 4 of autotransformer 3 will ultimately determine the voltage which will be supplied to the primary of transformer 5. For example, if the tap 4 reaches that point on the autotransformer winding connected to supply terminal 1, no voltage will be supplied to transformer 5. Conversely, if the variable tap 4 approaches the point connected to terminal 2, full supply line voltage will be applied to the transformer 5.

The variable tap 4 is mechanically positioned by a two-phase electric motor 12 with windings in electrical quadrature. One of these windings 12–*a* has a fixed current applied thereto through a capacitance 13 from one side of the line to the center tap of the autotransformer 3. Quadrature winding 12–*b* is coupled between the center tap of the autotransformer and the junction of the reactance windings of saturable reactor 11 and ballast reactor 14. Both windings 12–*a* and 12–*b* must be energized to provide rotation of the motor 12.

Saturable reactor 11 has three magnetic paths in parallel, formed by a three-legged core. Two opposed, series-connected reactance windings 11–*a* and 11–*b* are symmetrically displaced about the outside legs of the reactor 11 core. Windings 11–*a* and 11–*b* are, in turn, connected in series with a fixed reactor 14; the series combination of reactors 11 and 14 is connected to the alternating current supply line. The amount of inductive reactance presented by windings 11–*a* and 11–*b* of reactor 11 is dependent upon a control winding 11–*c* magnetically coupled to the middle leg of the reactor and having a unidirectional current flowing therein. This unidirectional current will induce a direct current saturating flux in the core of the reactance, varying the reluctance and causing the inductive reactance of windings 11–*a* and 11–*b* to vary in accordance therewith. The series combination of saturable reactor 11 and reactor 14 divide the supply line voltage in accordance with the relative ratio of their impedance. As the reactance of windings 11–*a* and 11–*b* varies, their impedance varies, and the relative ratios of alternating voltages thus vary responsive to the control winding 11–*c*.

When the regulatory system is in a quiescent state, the voltage drop appearing across the regulator tubes 7 will have a given magnitude. The windings of saturable reactor 11 and ballast reactor 14 are so arranged that when this given voltage is applied to the control winding 11–*c* of the saturable reactor 11, the impedance of the reactance windings 11–*a* and 11–*b* of saturable reactor 11 and the impedance of reactor 14 are substantially equal. The resultant voltage across the reactance windings of saturable reactor 11 or reactor 14 will have subtantially the same vectoral magnitude. When the quiescent condition of the regulatory system provides voltages of equal vectoral magnitude across the reactance windings of reactors 11 and of reactor 14, quadrature winding 12–*b* has substantially no voltage applied thereto. Both ends of motor winding 12–*b* will thus be at a mid-point with respect to the alternating current supply line voltage. On one side of winding 12–*b* is the mid-point reached between reactance windings of reactor 11 and reactor 14; on the other side, connection is made to the mid-point tap of autotransformer 3.

When a non-quiescent condition indicative of a load current change occurs in the regulatory system, a new value of voltage drop appears across the regulator tubes 7. This new voltage drop will alter the saturation condition of reactor 11 and, in turn, will cause the impedance offered by windings 11–*a* and 11–*b* to change correspondingly. The relative voltages across windings 11–*a* and 11–*b* and reactor 14 will no longer be equal and a resulting voltage is supplied to quadrature winding 12–*b*. Both windings 12–*a* and 12–*b* of the motor 12 will thus be energized. Capacitance 13 aids in correcting the phase of the current supplied to winding 12–*a*, providing a quadrature relation. Motor 12 now rotates, driving the variable tap 4 to some new position on the winding of autotransformer 3.

To illustrate the operation of the system according to the invention: if the current drawn by the load is assumed to increase, the regulator tubes 7 will attempt to correct the load current by increasing the apparent resistance offered by the space current path. This increased resistance and the resulting increased voltage drop is reflected to the control winding 11-*c* of reactor 11. In turn, the reactance of windings 11-*a* and 11-*b* will decrease, and motor 12 turns in a given direction of rotation. This direction of rotation will be such as to cause the variable tap 4 to approach a point on the autotransformer winding nearer to terminal 1, reducing the alternating voltage applied to transformer 5 and thus reducing the resultant output voltage of rectifier 6. The reduction in rectifier output voltage should be an amount appropriate for corresponding reduction of the load current previously assumed as increasing. The operation of the regulatory system as described will continue until the voltage drop across the regulator tubes 7 again reaches the quiescent value; the regulatory system will then return to a dormant condition.

Assuming now a drop in load current, the reactance of windings 11-*a* and 11-*b* increases and the motor rotates in the opposite direction to that previously described; the variable tap 4 will be brought to a point on the winding of autotransformer 3 nearer the terminal 2. This will increase the alternating voltage supplied to transformer 5, causing the desired increase in rectifier output voltage to compensate for the load current drop.

Reactor 9 and capacitance 10 form part of a filter arrangement. The saturated condition of reactor 11 and the non-linearity inherent in its operation causes harmonics of the alternating current supply frequency to appear across the windings 11-*a* and 11-*b*. These harmonics, especially the third harmonic, would be found reflected to the load through winding 11-*c* were it not for the filter arrangement comprising 9 and 10. Capacitance 15 is also employed to remove undesired harmonics of the power line frequency across winding 12-*b*. It may be desirable to supplement capacitance 15 by providing inductance 15-*a* in series with 15; a single harmonic, such as the third, of large magnitude can thereby be eliminated. Harmonics tends to cause overheating in the motor 12, interfering with the operation of the regulatory system.

Referring to Fig. 2, a modification of a portion of the circuit shown in the dotted enclosure of Fig. 1 is here shown. In lieu of the single autotransformer 3 employed in the circuit of Fig. 1, two autotransformers 16 and 17 are utilized. As with autotransformer 3, autotransformer 16 is provided with a fixed center tap; both autotransformers 16 and 17 have variable taps thereon. A center-tapped reactor 18 is connected between the variable taps of the autotransformers 16 and 17. Mid-point tap 19 on reactor 18 is connected to the terminal of transformer 5. Autotransformers 16 and 17 are connected in parallel across the alternating current supply line. The two-phase motor 12 and its accompanying elements are connected to autotransformer 16 in the same manner as described in relation to autotransformer 3.

A change in output load current results in the operation of two-phase motor 12 in the manner described with reference to the circuit of Fig. 1. However, two-phase motor 12 is now connected to the sliding taps on both autotransformers 16 and 17 and will vary both simultaneously. When transformers 16 and 17 are sharing the load equally, the magnetomotive forces induced in the core of the intertransformer reactor 18 will oppose and cancel; there will be substantially no resultant flux produced in the core of this reactor. In the event that one or the other of autotransformers 16 and 17 should fail in operation, the load current of the rectifier system will pass through one-half of the winding of the reactor 18 and develop a resultant flux in the one. Each half of the winding will then have an alternating voltage developed thereon. If the energizing coil of a relay 20 is placed across one-half of the reactor winding, the appearance of the alternating voltage across reactor 18 upon failure of one of the autotransformers 16 and 17, will operate relay 20. Operation of relay 20 may be used to close an alarm circuit 21. Failure of one of the autotransformers 17 or 16 will thereupon give warning.

Referring now to Fig. 3, the alternating current supply is applied from terminals 1 and 2 to a transformer 5 in series with the windings 22-*a* and 22-*b* of reactor 22. As in the case of the circuit shown in Fig. 1, the alternating current supply is rectified by bridge rectifier 6 and supplied through a group of paralleled thermionic discharge tubes 7 or similar space current devices and a resistance 8, to the load 28. Cooperation between elements 5, 6, 7 and 8 to produce the desired rectified output has been described with reference to Fig. 1. The regulator tubes 7 will compensate for variations in load current over an operating range of tubes 7; these variations are reflected, in turn, as varying voltage drops across the anodes and cathodes of the regulator tubes 7. As before, these varying voltages are a function of the magnitude of the necessary correction and are utilized to assist the regulator tubes 7 in maintaining constant load current output. The voltage variations are applied through filters 9 and 10 as previously, and thence to the control winding 23-*c* of a saturable reactor 23.

One possible form of construction for reactor 23 employs a three-legged core and correspondingly, three magnetic paths in parallel. Symmetrically displaced about the core are two center-tapped alternating current windings 23-*a* and 23-*b*. These windings are connected together parallel-opposed; the parallel combination is in series with a reactor 24 across the alternating current supply terminals 1 and 2. Depending upon the relative impedance of reactor 24 and windings 23-*a* and 23-*b* of reactor 23, a voltage will be developed across the latter two windings.

Changes in load current will cause voltage drop variations to be produced across the regulator tubes 7, ultimately causing a unidirectional current to flow through the control winding 23-*c* of transformer 23. This current develops a direct current flux in the core of the reactor 23, changing the magnetic saturation and reluctance thereof. The change in reluctance alters the reactance of the windings 23-*a* and 23-*b*, and therefore the voltage appearing thereon.

Windings 23-*a* and 23-*b* are connected to the anodes of a full wave, grid-controlled rectifier comprising thermionic discharge rectifier tubes 25-*a* and 25-*b*. The cathodes of these rectifier tubes are connected together and to one side of a control winding 22-*c* of reactance 22. Reactance 22 has a three-legged core, and three magnetic paths in parallel. Two reactance windings 22-*a* and 22-*b* are symmetrically displaced about the core on the two outside legs and are connected together in series-opposition. The magnitude of reactance 22 is controlled by a unidirectional current flowing through the control winding 22–c controlling core saturation and reluctance. As the voltage developed at the output of full wave rectifiers 25–a and 25–b increases or decreases, a corresponding unidirectional current flows through the winding 22–c.

For example, a rise in load current and subsequent increase in the voltage drop appearing across the regulator tube 7 causes an increase in unidirectional current flow through the winding 23–c of transformer 23. The direct current magnetic saturation and reluctance of the core of transformer 23 is thereupon increased; the reactance of windings 23–a and 23–b will be reduced. Such a reduction in reactance causes a corresponding decrease in the impedance of these windings; the voltage appearing across windings 23–a and 23–b will be reduced by virtue of the change in impedance ratio between the latter windings and reactor 24. A rise in the load current thus ultimately results in a decrease in the voltage presented to the full wave rectifiers 25–a and 25–b; the unidirectional current through winding 22–c is thereupon lowered. As windings 23–a and 23–b are always connected across the line in series with reactance 24, the quiescent condition of the regulatory system will produce a given value of current flow through winding 22–c. In the example stated, it is this given value of current which will be diminished by the increase in load. Such a diminishing, in turn, increases the magnitude of the reactance of windings 22–a and 22–b. Inasmuch as the primary of transformer 5 and windings 22–a and 22–b are connected in series across the line, the voltage across either of these elements will depend upon the ratio of impedances between them. If the impedances of windings 22–a and 22–b increase through an increase in reactance, the voltage presented across the primary of transformer 5 will drop. This results in a depression of the output voltage of the rectifier 6 and of the load current, compensating for the originally assumed increase in load current.

Similarly, a decrease in load current can be shown to decrease the direct current saturation of the core of transformer 23, thereupon increasing the output voltage of the full wave rectifiers 25–a and 25–b and increasing the direct current saturation of the core of reactance 22. This will, in turn, increase the output of the bridge rectifier 6 and the load current, tending to compensate for the decreased output load current.

The output of the full wave rectifier 25–a and 25–b is also connected to the series combination of a varistor 26 and a capacitance 27. The junction of the varistor 26 and capacitance 27 is connected through current limiting resistors to the control grids of rectifiers 25–a and 25–b. Varistor 26 is a circuit element having a given low resistance to the flow of current in one direction called the "forward" current, and a relatively high resistance to the flow of current in the opposite direction called the "back" current. Such a varistor may well be composed of a metallic disc rectifier 29 employing a semiconductive material such as selenium, in parallel with a relatively high value conventional resistance 30. Operation of the varistor is shown in Fig. 4–a and Fig. 4–b; a majority I_1 of the total current I, in Fig. 4–a, passes through the metallic disc rectifier 29 with little resistance. A flow of current, I_2, in Fig. 4–b in the opposite direction, cannot pass through the metallic disc rectifier and must find its way through the resistance 30.

Referring again to Fig. 3, when the varistor 26 and capacitance 27 are in steady state conditions, represented by a constant output of full wave rectifiers 25–a and 25–b, capacitance 27 will have assumed a charging voltage equivalent to the full wave rectifier output voltage. As a result, no voltage will appear across the varistor 26, and the grids of the rectifiers 25–a and 25–b will have substantially zero voltage difference with respect to their cathodes. However, changes occur in the output voltage of the rectifiers 25–a and 25–b, resulting from a compensatory signal, in the manner previously described. If the output voltage of the full wave rectifier should drop, capacitance 27 will seek to discharge a corresponding portion of the voltage appearing across it. This discharge of voltage will establish a current flowing in the forward direction of the varistor 26. As the resistance of the flow of current in the forward direction of the varistor is small, the condenser will discharge rapidly, and substantially no voltage will appear between the grids and cathodes of rectifier tubes 25–a and 25–b. However, when the voltage rises across the output of the full wave rectifiers, the capacitance 27 will take an increased charge. This increased charge necessitates a back flow of current through the varistor; a period of time dependent upon the back resistance of the varistor 26, and ultimately upon the value of resistance 30 and capacitance 27, will be required to achieve the steady state charge. During the period of time required for charging condenser 27, a negative voltage will appear upon the control grids of rectifiers 25–a and 25–b, limiting the flow of current through these rectifiers and thus providing a time lag in the operation of the circuit.

The overall effect of the grid control of the rectifiers 25–a and 25–b is to insert a time lag in the operation of the compensating circuits. Such a time lag is useful in elimination of oversensitivity in the control circuit; oversensitivity results in a "hunting" condition; inability of the control system to arrest itself at the quiescent point, the quiescent point being the condition at which the load current is maintained at its desired value.

It is obvious that the scope of the invention is not limited to the specific embodiments described, and that the invention may be employed in arrangements other than those given by way of example.

What is claimed is:

1. A direct current power supply for supplying stabilized current to a load comprising, a rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from said rectifier to a load, said circuit having two parallel branch paths through which said rectified current is transmitted to the load, one of said branch paths comprising means responsive to the current supplied to the load for controlling at least in part said load current, and means for controlling the alternating voltage from said source impressed upon said rectifier, said latter means comprising a saturable reactive device having a core and a saturating winding thereon and means for connecting said saturating winding in the free parallel branch path.

2. In a direct current power supply circuit for supplying stabilized current to a load, including a rectifier to supply direct current from a source

of alternating current and a series regulating device having a variable resistance responsive to the output current of the rectifier for controlling the said load current, the said circuit comprising a reactive element having a magnetically saturable core, a saturating winding and a variable impedance winding, means to couple the saturating winding of the said reactive element to the variable resistance of the series regulating device, and means for controlling the magnitude of the source of alternating current applied to the rectifier in accordance with the magnitude of the impedance of the variable impedance winding of the said reactive element.

3. A power supply system according to claim 2 characterized in that the means for controlling the magnitude of the source of alternating current applied to the rectifier comprises a mechanically variable multiratio transformer interposed between the source of alternating current and the rectifier, an electric motor linked mechanically to the said multiratio transformer, and means to supply the electric motor with a source of electric energy responsive to the magnitude of the impedance of the variable impedance winding of the said reactive element.

4. A power supply system according to claim 2 characterized in that the means for controlling the magnitude of the source of alternating current applied to the rectifier comprises a rectifier input transformer having a secondary winding connected to the rectifier and a primary winding, a second reactive element having a magnetically saturable core, a saturable winding and a variable impedance winding, means to couple the variable impedance winding of the said second reactive element in series with the primary of the said transformer to the source of alternating current, an auxiliary rectifier having an input responsive to the variable impedance winding of the first-mentioned reactive element, and means to couple the output of the said auxiliary rectifier to the saturating winding of the said second reactive element.

5. In combination, a rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from the said rectifier to a load, said circuit comprising an electron discharge path, having a cathode, grid and anode, means to couple the anode-cathode circuit of the said electron discharge path in series with the said circuit, means to derive a control voltage in the grid-cathode circuit of the said electron discharge path proportional to the current supplied to the load, a reactance element having a magnetically saturable core, an impedance winding and a direct current saturation control winding, means to couple the control winding of the said reactance element in parallel with the said electron discharge path, and means to control the alternating voltage from the said source impressed upon the said rectifier, said latter means being responsive to the magnitude of the impedance of the impedance winding of the said reactive element.

6. In combination, a rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from the said rectifier to a load, said circuit comprising an electron discharge path, having a cathode, grid and anode, means to couple the anode-cathode circuit of the said electron discharge path in series with the said circuit, means to derive a control voltage in the grid-cathode circuit of the said electron discharge path proportional to the

current supplied to the load, a reactance element having a magnetically saturable core, an impedance winding and a direct current saturation control winding coupled in parallel with the said electron discharge path, means to derive a control voltage responsive to the magnitude of the impedance of the impedance winding of the said reactance element, and means to regulate the alternating voltage from the said source impressed on the said rectifier in accordance with the said control voltage.

7. In combination, a main rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from the said main rectifier to a load, said circuit comprising an electron discharge path, having a cathode, grid and anode, means to couple the anode-cathode circuit of the said electron discharge path in series with the said circuit, means to derive a control voltage in the grid-cathode circuit of the said electron discharge path proportional to the current supplied to the load, a first saturable reactor having an impedance winding and a direct current saturation control winding coupled in parallel with the said electron discharge path, a fixed reactor connected to the supply source through the impedance winding of the said first saturable reactor, an auxiliary rectifier having its input coupled to the impedance winding of the said first saturable reactor, a second saturable reactor having a direct current control winding and an impedance winding in series with the alternating current supply source to the main rectifier, and means to couple the direct current control winding of the said second saturable reactor to the output of the said auxiliary rectifier.

8. In combination, a rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from the said rectifier to a load, said circuit comprising an electron discharge path, having a cathode, grid and anode, means to couple the anode-cathode circuit of the said electron discharge path in series with the said circuit, means to derive a control voltage in the grid-cathode circuit of the said electron discharge path proportional to the current supplied to the load, a reactor having a magnetically saturable core, a direct current saturation control winding coupled in parallel with the said plurality of thermionic discharge tubes and an impedance winding, means to derive a control voltage responsive to the magnitude of the impedance of the impedance winding of the said reactance element, a variable tap transformer connected between the said rectifier and source of alternating current, an electric servomotor mechanically linked to the said variable tap transformer, and means to excite the said electric servomotor in accordance with the said derived control voltage.

9. In combination, a rectifier for rectifying current from an alternating current supply source, a circuit for transmitting rectified current from the said rectifier to a load, said circuit comprising a plurality of thermionic discharge tubes, having each a cathode, grid and anode, means to couple the anode-cathode circuits of the said thermionic discharge tubes to each other in parallel and together in series with the said circuit, means for deriving and impressing upon the grid-cathode circuit of the said thermionic discharge tubes a control voltage proportional to the current supplied to the load, a saturable reactor having a direct current saturation control

winding coupled in parallel with the said plurality of thermionic discharge tubes and an impedance winding, a fixed reactor connected to the source of alternating current through the impedance winding of the said saturable reactor, a polyphase motor having windings in quadrature, means to excite one of the windings of the said motor in a given phase, an autotransformer connected between the said rectifier and the source of alternating current, said autotransformer having a variable tap mechanically linked to the said motor, and means to couple the free winding of the said motor in parallel with the impedance winding of the said reactor, whereby the said motor is excited in quadrature.

10. Apparatus as in claim 9 having a second autotransformer connected between the said rectifier and the source of alternating current, a balancing reactor having portions thereof coupled discretely in series with the said autotransformers, and an alarm relay coupled in parallel with one of the said portions of the balancing reactor.

11. In a constant current, direct current power supply system including a rectifier, a transformer, a source of alternating current supplied to the rectifier through the said transformer, a load coupled to the output of the said rectifier, and a saturable reactor having an impedance winding responsive in magnitude of impedance to variations in the load current, in combination, an auxiliary rectifier comprising at least one thermionic discharge tube having a cathode, grid and anode, means to connect the anode-cathode circuit of the said thermionic discharge tube in series with the impedance winding of the said saturable reactor, a fixed reactor connected to the source of alternating current in series with the impedance winding of the said saturable reactor, a varistor, a capacitance coupled to the output of the said auxiliary rectifier in series with the said varistor, means to connect the junction of the said varistor and resistance to the control grid of the said thermionic discharge tube, an auxiliary saturable reactor having a direct current control winding and an impedance winding interposed between the alternating current supply and the said transformer, and a coupling of the direct current control winding of the said auxiliary saturable reaction to the output of the said auxiliary rectifier.

12. In a constant current, direct current power supply system including a rectifier, a source of alternating current supplied thereto, a load coupled to the output of the said rectifier, and a saturable reactor having an impedance winding responsive in magnitude of impedance to variations in the load current, in combination, a reactor coupled to the source of alternating current in series with the impedance winding of the said saturable reactor, a quadrature-wound motor having one winding excited in a given phase, an autotransformer coupled between the source of alternating current and the rectifier, said autotransformer having a variable tap thereon coupled mechanically to the said motor, and means to couple the free winding of the said motor between the junction of the said reactor and saturable reactor and a point electrically removed with respect to the source of alternating current.

JAMES A. POTTER.

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