Nov. 19, 1957 M. H. HAYES 2,814,014

VOLTAGE REGULATION

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Fig. 1.

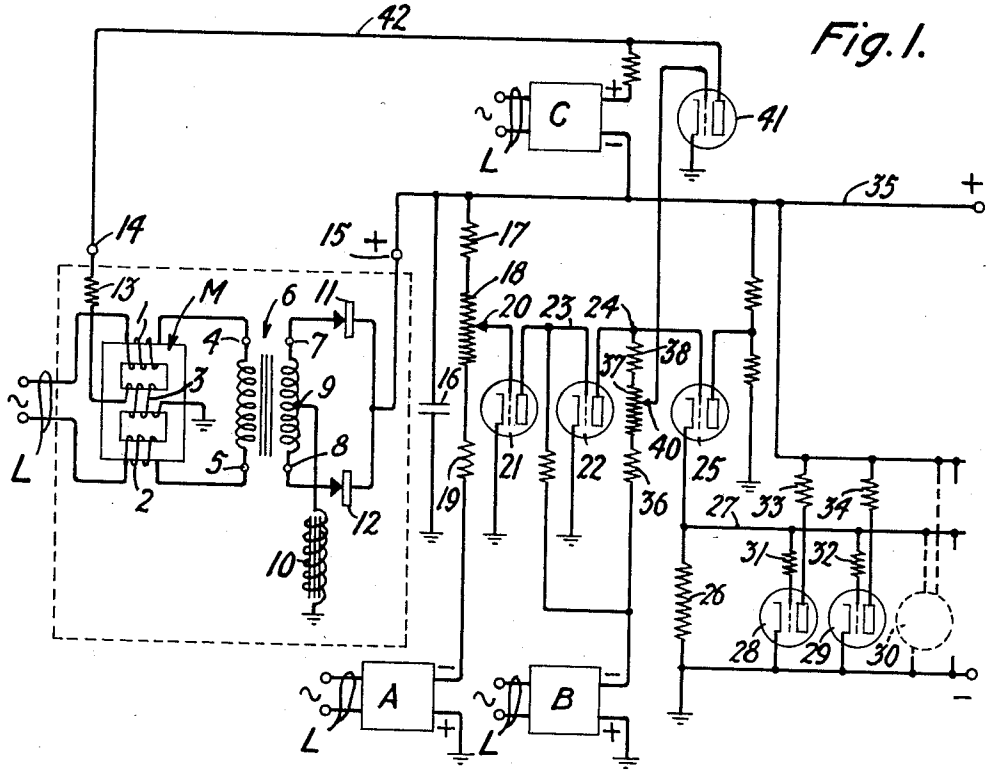


Fig. 2.

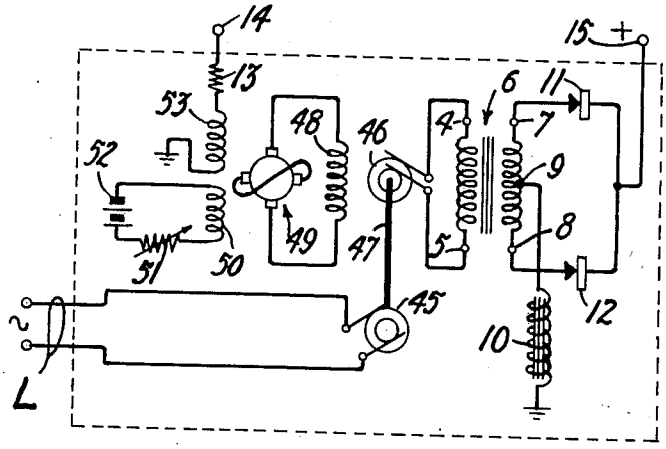
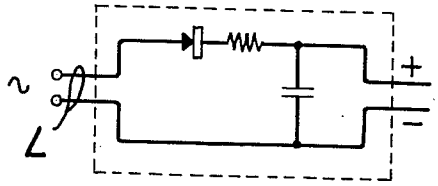


Fig. 3.



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VOLTAGE REGULATION

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This invention relates to voltage regulating apparatus and more specifically to an improved means for supplying direct current from a source of very low impedance at a constant potential.

In the electrical arts generally, and particularly in the computer, automatic control, instrumentation and communication arts, many well known and widely used circuits require constant potential direct current power. In order to achieve accurate computation, reliable control, accurate instrumentation or undistorted communication, it is usually necessary that ample direct current power supplied to such circuits be maintained at a constant potential regardless of supply voltage fluctuations or load impedance variations. It is also desirable that such power be supplied with a minimum of waste.

Various means for effecting regulation are well-known. Thermionic emission devices placed in series with a load usually offer rapid response to voltage fluctuations, but such devices are capable of supplying only small amounts of current. Gaseous discharge devices such as thyratrons are usually capable of supplying greater current, but have a disadvantageous time delay in response. Since thyratron controls effect changes in output voltage level by varying the time of conduction of the thyratron during each cycle, voltage fluctuations which occur at frequencies higher than that of the input supply to the thyratron are not smoothed out by a thyratron control.

Shunt regulating tubes provide an extremely rapid correction of high speed voltage fluctuations, and because load current need not flow through such tubes, ample regulation may be provided for high current power supplies using such tubes. However, due to the limited current capacity of a shunt connected regulating tube, it is necessary that such tubes be maintained at optimum operating potentials in order to correct rapid voltage fluctuations. For example, if a shunt regulating tube is conducting near saturation in order to correct a gradual or maintained decrease in load impedance, a rapid variation in load impedance or input potential may not be adequately and quickly corrected by the shunt tube. The present invention overcomes the above mentioned disadvantages of prior art devices by providing in combination a thermionic-emission shunt regulator capable of extremely rapid response to voltage fluctuations, and a magnetically-controlled source regulating means operable to maintain the shunt regulator at its optimum operating point, so that wide excursions in load impedance or supply voltage do not affect control response.

It is therefore a primary object of the invention to provide an improved direct current power supply which will present an extremely low source impedance to a load.

It is another object of the invention to provide an improved direct current power supply capable of supplying large amounts of current at a constant potential, regardless of the rate of input supply voltage fluctuations or load impedance variations.

A more particular object of the invention is to provide an improved full-wave rectified direct current power

supply deriving its power from any alternating current source and delivering a constant potential direct current output irrespective of fluctuations in the alternating current source potential or variations in the direct current output load.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the features of construction, combinations of elements, and arrangements of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference may be had to the following detailed description taken in connection with the accompanying drawing, in which certain well-known elements are shown in block diagram form for the sake of clarity, and wherein corresponding parts are identified by like reference characters:

Fig. 1 is an electrical schematic diagram of one preferred embodiment of my invention;

Fig. 2 is an electrical schematic diagram of an alternative embodiment of my invention, and

Fig. 3 illustrates one form of internal reference voltage source which may be employed for furnishing amplifier anode voltages in practice of my invention.

Referring now in greater detail to Fig. 1 there is shown a pair of input terminals L to which an alternating supply voltage may be connected. The voltage from the supply is applied through reactance windings **1** and **2** of saturable reactor M to terminals **4** and **5** of the primary winding of transformer **6**. The control winding **3** of saturable reactor M is connected as shown to ground and through resistance **13** to terminal **14**. As is well-known in the electrical arts, the reactance of windings **1** and **2** may be varied by variation in current supplied to control coil **3**. Hence it will be apparent that by variation in voltage applied to terminal **14**, the voltage applied to the primary winding of transformer **6** may be varied. The secondary terminals **7** and **8** of transformer **6** are connected in conventional manner to a full-wave rectifying circuit comprising selenium rectifiers **11** and **12**. Vacuum diodes or gaseous rectifiers may be substituted for selenium rectifiers **11** and **12**. The positive output terminal **15** of the rectifying circuit is connected to conductor **35**. The negative output terminal **9** of the rectifying circuit is connected through a conventional filter choke **10** to ground. Hence the direct current output voltage of the power supply appears between conductor **35** and ground, and the load may be connected thereto. Capacitor **16** may be connected between conductor **35** and ground to aid in smoothing out voltage variations.

Conductor **35** is also connected through resistor **17**, potentiometer **18** and resistor **19** to the negative terminal of a direct current voltage reference source A, which may comprise a battery or any other source of constant voltage. The positive terminal of reference voltage source A is connected to ground. In operation of the invention, potentiometer **18** is adjusted so that its wiper arm **20** lies very nearly at ground potential. The voltage on the wiper arm **20** is connected as shown to the control grid of a direct-coupled amplifier triode **21**, the cathode of which is connected to ground. Since the potential of reference source A remains constant, voltage excursions of supply conductor **35** will produce an error signal between grid and cathode of amplifier **21**, raising or lowering the anode voltage of triode **21**. The anode voltage is direct coupled through conductor **23** to the control grid of a similar triode amplifier **22**. Amplifiers **21** and **22** are supplied with anode voltage from a voltage supply source B, which may take the form shown in Fig. 3.

An increase in voltage on conductor **35** will cause a

decrease in voltage on conductor 23 and an increase in voltage on conductor 24. The rise in voltage on conductor 24 will cause a rise in voltage at the wiper arm 40 of potentiometer 37 and at the control grid of a cathode-follower triode 25. The increased current through cathode follower 25 will cause an increased voltage on conductor 27 and the grids of shunt regulator tubes 28, 29, 30. The value of cathode resistor 26 is chosen so that the shunt regulator thermionic emission tubes 28, 29, 30 are normally-biased in the middle region of their characteristic curve. A rise in voltage on conductor 27 makes the shunt regulator tubes 28, 29, 30 conduct more plate current, and the increased current drain causes a lower voltage to appear on conductor 35 due to the increased voltage drop through the impedances of rectifiers 11 and 12, transformer 6 and saturable reactor M. Since the amplified error signal applied to the grids of the regulator tubes 28, 29, 30 is direct-coupled from wiper arm 20, the corrective action of the regulator tubes will be instantaneous, regardless of the frequency of the voltage excursion on conductor 35.

If the voltage excursion on conductor 35 is of great magnitude, the shunt regulator tubes 28, 29, 30 would be cut off or saturated, and hence made ineffective to control rapid voltage fluctuations on conductor 35, were it not for the novel source regulating means provided in the invention to maintain the shunt regulator tubes at their optimum operating point. The rise of voltage on the arm 40 of potentiometer 37 causes greater current to flow through triode 41, decreasing the voltage on conductor 42 and hence decreasing the current supplied to the control coil 3 of saturable reactor M through terminal 14 and resistor 13. Since the control coil 3 has appreciable inductance, current changes in the coil will occur more slowly, and hence the corrective action caused by the saturable reactor will occur only if the voltage excursion on conductor 35 persists for an appreciable period of time.

It is to be understood that any desired number of shunt connected thermionic emission devices, such as thermionic valves 28, 29, etc., may be employed. Shunt regulator valves 28, 29, etc. are preferably low impedance high current thermionic tubes such as Type 6AS7.

Reference voltage source C, which applies anode potential to triode 41, may comprise a battery or any other source of constant voltage, as for example a selenium rectifier source as shown in Fig. 3.

Reference is now had to Fig. 2 of the drawing which discloses an alternative form of magnetic input control which may be employed in lieu of the saturable reactor M of Fig. 1. In Fig. 2 the line L is connected to a motor 45 which drives a dynamoelectric generator 46 through a common shaft 47. In the circuit of Fig. 2, the generator 46 is represented as an alternator, having its output connected to the primary terminals 4 and 5 of high voltage transformer 6. The secondary terminals 7 and 8 are connected through rectifiers 11 and 12 to terminal 15, and the center tap 9 is connected through choke 10 to ground in the same manner as shown in Fig. 1. Alternator 46 has a field coil 48 which is connected to the output terminals of an amplidyne generator 49. An excitation coil 50 is connected through a variable resistor 51 to a source of D. C. potential 52, here represented as a battery although it will be understood that any other D. C. excitation source may be employed, as for example the source illustrated in Fig. 3. A second excitation coil 53 is connected between ground and resistor 13, the other side of which connects to terminal 14, conductor 42 and the anode of tube 41 in Fig. 1.

When terminals 14 and 15 in the circuit of Fig. 2 are connected to the corresponding terminals of Fig. 1, in lieu of the saturable reactor input means M, a rise in voltage at the anode of tube 41 which may result from an incremental decrease in potential on conductor 35 as described above in reference to Fig. 1, will cause increased current to flow through excitation coil 53 of amplidyne generator 49, thus increasing the excitation current through field coil 48 of alternator 46 and resulting in a corresponding increase in voltage applied to the primary terminals 4 and 5 of transformer 6. A corresponding incremental increase in D. C. output voltage occurs to maintain the output constant. Conversely, any decrease in voltage at the anode of tube 41, which may be caused by an incremental increase in voltage on conductor 35 as described above, will result in a decrease of excitation current through coil 53, with a corresponding decrease in voltage applied to the primary terminals 4 and 5 of transformer 6, thus maintaining the D. C. output voltage on conductor 35 constant.

Variable resistor 51, in series with excitation coil 50 and excitation source 52 of Fig. 2, provides a convenient means for manually adjusting the excitation current through field coil 48 of alternator 46, and hence for adjusting the potential applied to primary terminals 4 and 5 of high voltage transformer 6.

It is to be understood that while I have shown an amplidyne generator 49 as connecting means between excitation coil 53 and alternator field coil 48, the amplidyne 49 may be omitted entirely, if desired, and the connection from resistor 13 to coil 53 may be transferred directly to excitation coil 48. If this is done, then the other end of field coil 48 should be connected to ground, so that variations of anode potential on tube 41 and conductor 42 will be directly reflected in the excitation of generator 46.

One of the advantages afforded by the input circuit of Fig. 2 is that the power supply of the invention may be operated from either an A. C. or D. C. line source L, depending upon whether the motor 45 of motor-generator set 45—46 is an A. C. motor or a D. C. motor. By employing a universal A. C.-D. C. motor to drive generator 46, the power supply may be operated from either A. C. or D. C. line sources without requiring any change in the driving motor 45.

It will also be apparent to those skilled in the art that by employing a D. C. generator in lieu of the alternator shown at 46 in Fig. 2, the transformer 6, choke 10, and rectifiers 11 and 12 may be eliminated and the output of the D. C. generator may be connected directly between terminal 15 and ground. If this is done, terminal 14 should be connected to the field or excitation coil of the D. C. generator. In such a circuit, the combined input and output voltage regulating means still functions as described above to maintain a constant D. C. potential on output conductor 35. However, as the invention may find its greatest utility in high voltage power supplies, and because of the difficulty and expense of building satisfactory high voltage D. C. generators, it is considered that the use of an alternator 46 with a high voltage step-up transformer 6 and associated rectifiers 11 and 12 is preferable in this particular embodiment.

While I have shown thermionic emission devices as the elements 21, 22, 25, 28, 29 and 41 in my preferred embodiment, it is to be understood that other amplifying means, as for example cold cathode vacuum tubes or semiconductor devices, may be employed for these elements without departing from the scope of my invention.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of

the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described my invention, what I claim as new and desire to secure by Letters Patent is:

1. Voltage regulating apparatus for supplying constant potential to a load comprising a source of voltage connected to supply a load, a thermionic emission device connected in shunt circuit relationship with said load, said thermionic emission device having an anode and cathode connected to opposite terminals of said load and a control electrode, and being normally biased to conduct substantially in the middle region of its characteristic, means for comparing the voltage across said load with a reference voltage to produce an error voltage, means for amplifying said error voltage, means applying the amplified error voltage to said control electrode, and magnetically-controlled source regulating means connected to vary said source voltage so as to maintain the average potential on said control electrode substantially constant.

2. Apparatus as in claim 1 in which said magnetically-controlled source regulating means comprises a saturable reactor having reactance coils connected to vary said source voltage and a control coil responsive to the amplified error voltage to vary the reactance of said reactance windings.

3. Apparatus as in claim 1 in which said magnetically-controlled source regulating means comprises a dynamo-electric generator having excitation means responsive to the amplified error voltage to vary the output potential of said generator.

4. Voltage regulating apparatus comprising a source of voltage connected to supply a load, a thermionic emission device connected in parallel with said load, said thermionic emission device having an anode and cathode connected to opposite terminals of said load and a control electrode, means biasing said thermionic device substantially in the middle portion of its characteristic, means for deriving a first potential proportional to the deviation of the voltage across said load from a desired value, direct coupled amplifying means for amplifying said first potential and for applying the amplified potential to said control electrode, and variable impedance means responsive to said first potential for varying said source voltage so as to maintain the average current through said thermionic emission device substantially constant.

5. Voltage regulating apparatus of low source impedance for supplying constant potential to a load comprising a source of voltage connected to supply a load, a thermionic emission device connected in parallel circuit relationship to said load, said thermionic emission device having a cathode connected to a first terminal of said load, an anode connected through a resistance to an opposite terminal of said load, and a control electrode; said thermionic emission device being biased to substantially the middle region of its characteristic, a voltage reference source, means for comparing the voltage across said load with said voltage reference to obtain an error voltage, direct-coupled amplifying means to amplify said error voltage and to apply said amplified error voltage to said control electrode, and variable impedance control means of substantial time-constant responsive to said error voltage for varying said source voltage whereby the average current through said thermionic emission device is maintained substantially constant.

6. A constant potential direct current power supply comprising a magnetic inductor having motor drive means adapted for connection to a line source of electrical power, means coupling said magnetic inductor with potential responsive amplifying means, excitation means on said magnetic inductor for influencing the potential output thereof, means coupling the output of said amplifying means with said excitation means to effect opposite changes in instantaneous excitation corresponding to incremental variations in potential, and potential responsive variable load impedance means coupled with the output of said inductor to vary the current drain thereon directly with instantaneous incremental changes in the potential output thereof.

7. A constant potential direct current power supply comprising a saturable magnetic reactor having a pair of reactance coils and a separate control coil, means for connecting one end of each of said reactance coils to a source of alternating current, an electrical transformer, means connecting the opposite end of each reactance coil to the primary winding of said electrical transformer, electrical current rectifying means connected with the secondary of said transformer, potential responsive amplifying means connected with the rectified output potential from said rectifying means to magnify any incremental changes in the potential thereof, means coupling the output of said amplifying means to said reactor control coil to effect instantaneously an opposite change in said reactor output potential for each incremental change in said rectified output potential, and further potential responsive variable impedance means connected in shunt relation with said amplifying means and with said rectifying means to vary a shunt impedance across said rectified potential output inversely with said incremental changes in the potential thereof.

8. A constant potential direct current power supply comprising in combination an inductive alternator having motor drive means adapted for connection to a line source of electrical power, variable excitation means coupled with said alternator, electrical transformer means coupling the output of said alternator with electrical rectifying means to convert the current output from said alternator to a direct current potential, means connecting said rectified direct current potential with amplifying means adapted to magnify any instantaneous incremental variations in said direct current potential, means coupling the output of said amplifying means with said variable excitation means to effect opposite variation of excitation corresponding to incremental variations in said direct current potential, and further potential responsive variable impedance means connected in shunt relation with said rectified direct current potential and with said amplifying means to effect instantaneous variation in the current drawn from said rectifying means in direct proportion to instantaneous incremental variations in said direct current potential.

9. Voltage regulating apparatus for supplying constant potential to a variable load comprising, an input circuit adapted to be connected to a source of electrical power, variable impedance source regulating means connected to said input circuit, an output circuit adapted to be connected to a load, a thermionic emission device connected in shunt relationship with said output circuit, said thermionic emission device having an anode and a cathode connected to opposite terminals of said output circuit, a control electrode of said device connected with means normally biasing said device to conduct substantially in the middle region of its characteristic, means for comparing the voltage across said output circuit with a reference voltage to produce an error voltage, means for applying said error voltage to said source regulating means to vary the impedance thereof, and direct coupled amplifying means for applying amplified error voltages directly to the control electrode of said shunt connected thermionic device.

10. Voltage regulating apparatus for supplying constant potential to a variable load comprising, a variable impedance input circuit adapted to be connected to a power line, a potential responsive impedance control element in said input circuit, a low impedance output circuit adapted to be connected to a variable load, a thermionic emission device connected in shunt relationship with said output circuit, said thermionic emission device having an anode and cathode connected to opposite terminals of said output circuit, a variable potential bias means, a control electrode of said thermionic device connected to

said variable potential bias means, a reference potential source, means for comparing the voltage across said output terminals with said reference potential to produce an error voltage, means for amplifying said error voltage, means including said variable bias means for applying the amplified error voltage to the control electrode of said thermionic device to vary the bias thereof directly with variations of said error voltage, and further means connecting said amplified error voltage with said potential responsive control element to vary the impedance of said input circuit inversely with variations of said error voltage.

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