

Oct. 15, 1957

W. H. HENRICH

2,810,105

VOLTAGE REGULATOR

Filed May 19, 1953

4 Sheets-Sheet 1

FIG. 1

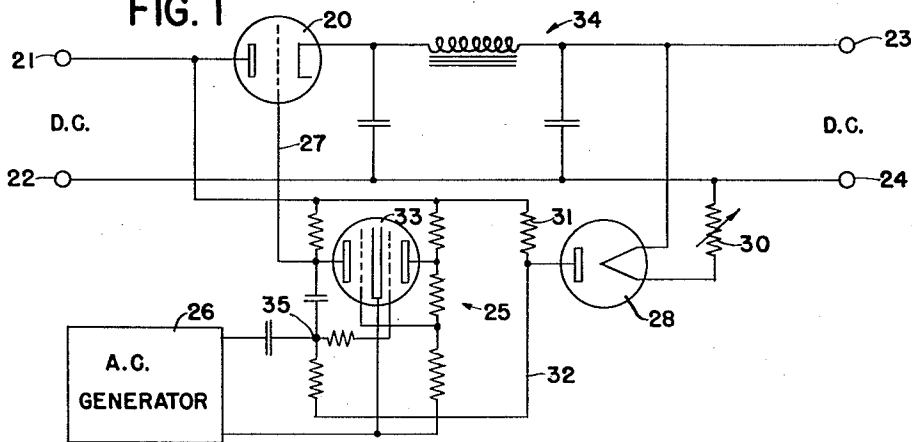


FIG. 2

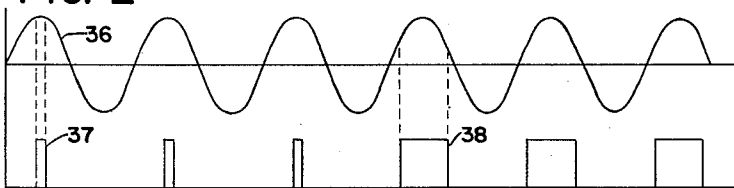


FIG. 3

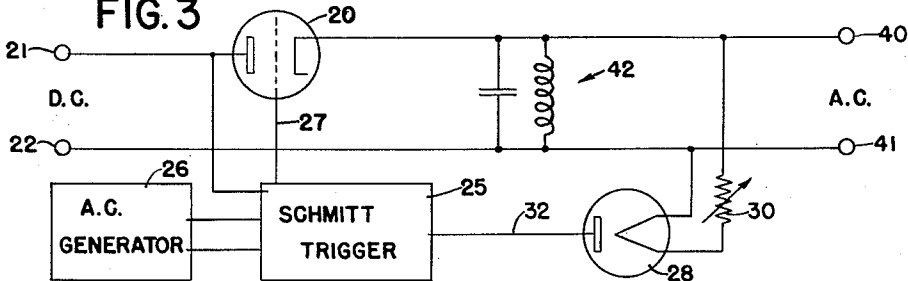
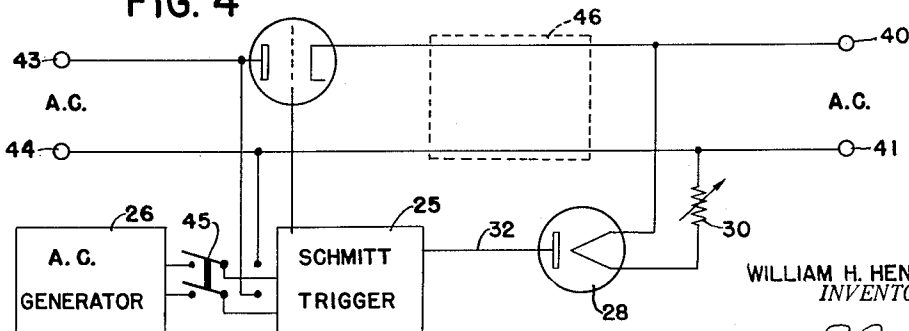


FIG. 4



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FIG. 5

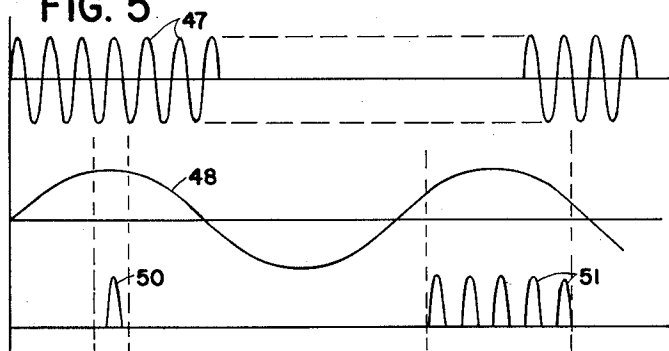


FIG. 6

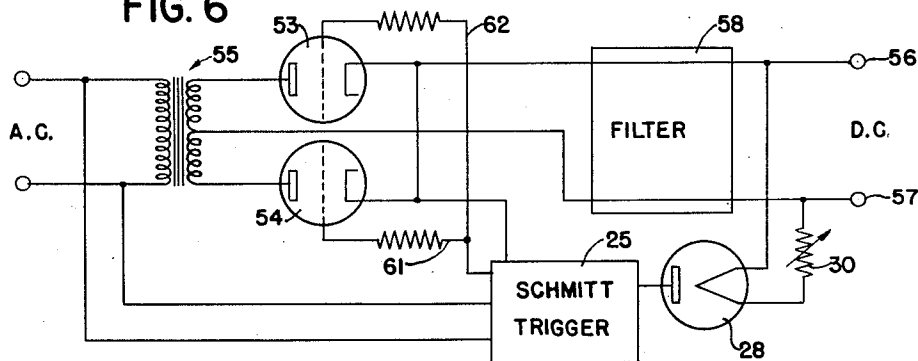


FIG. 7

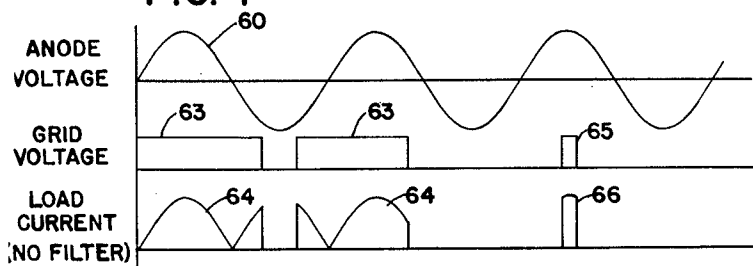
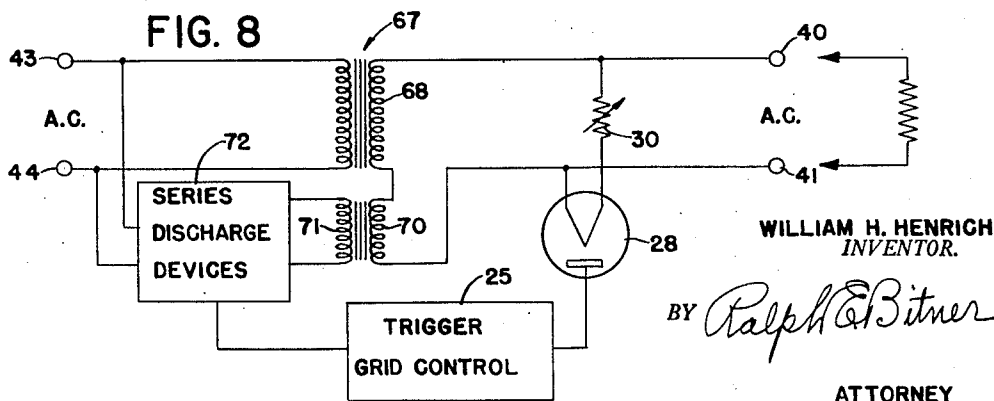


FIG. 8



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FIG. 9

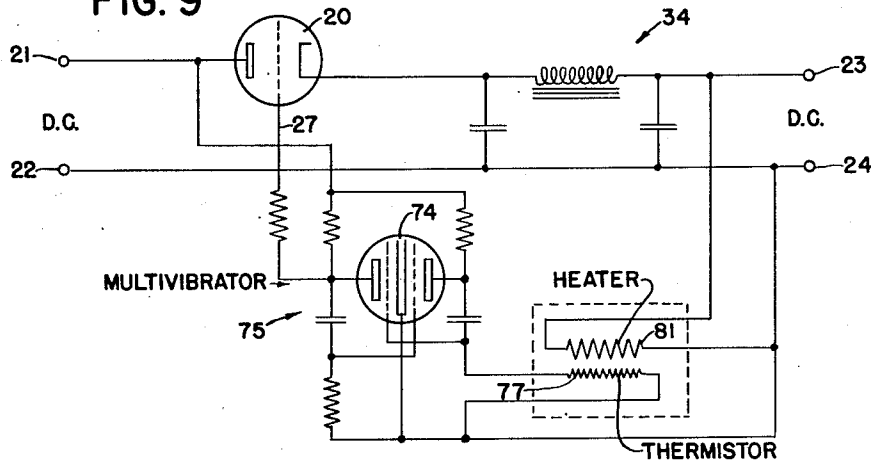


FIG. 10

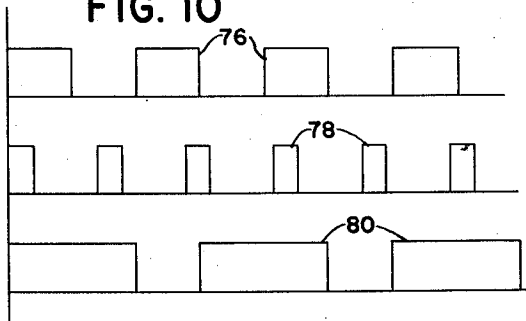


FIG. 11

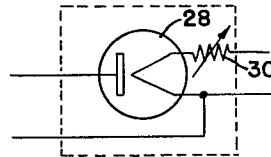
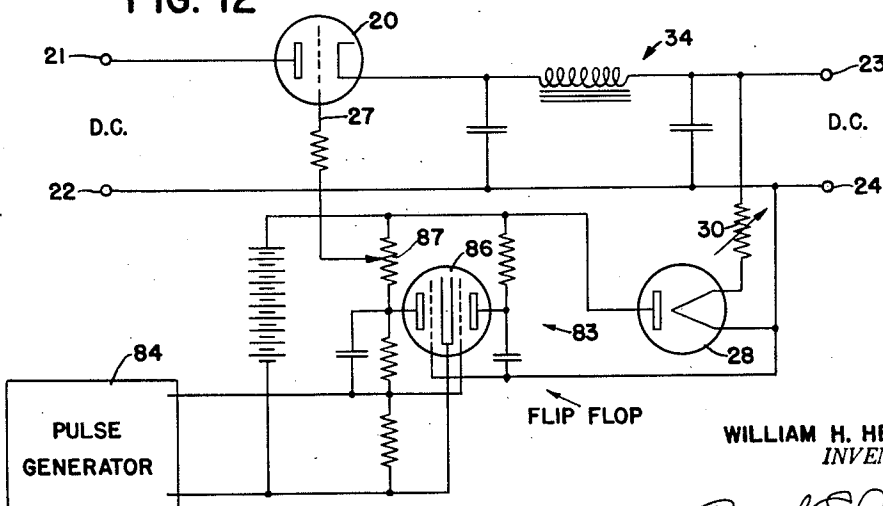


FIG. 12



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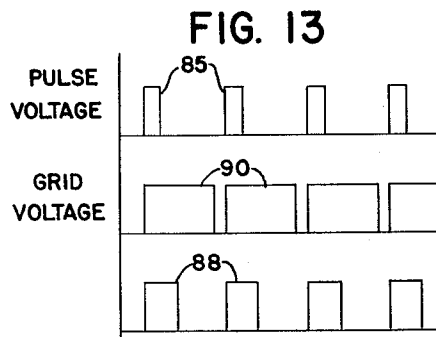
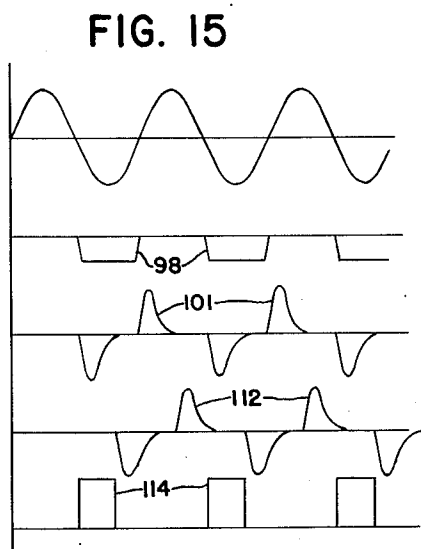
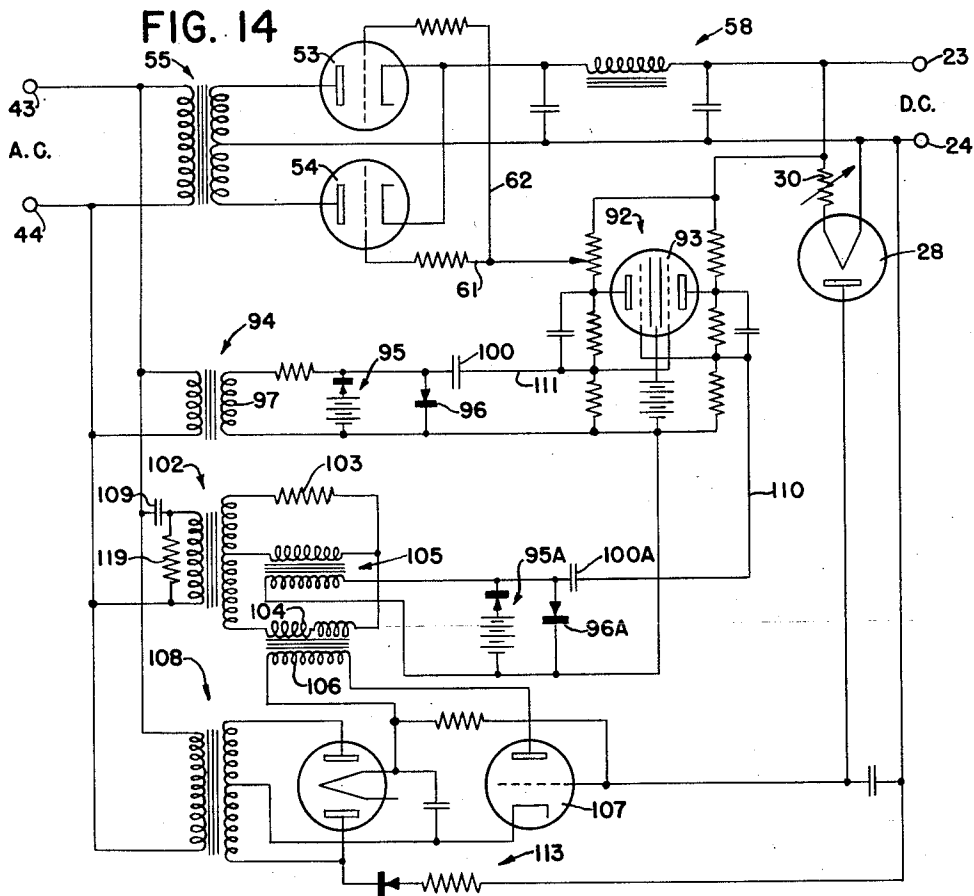
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## VOLTAGE REGULATOR

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Application May 19, 1953, Serial No. 355,927

3 Claims. (Cl. 323--22)

This invention relates to voltage regulators and has particular reference to a voltage regulator circuit using an electronic or electric controllable impedance as the series regulating component. The voltage regulator is designed for high efficiency operation.

Many circuits have been devised in which an electron discharge device is connected in series between the source of supply and a load circuit. This type of circuit uses one or more control electrodes to vary the impedance of the discharge device in accordance with the requirements of a sensing device which is placed in parallel connection with the load circuit in order to determine the load voltage. An obvious disadvantage of this type of circuit resides in the fact that the discharge device has a high resistance and therefore consumes a lot of power. This is especially true when the voltage of the source becomes high and the discharge device is controlled to present a higher resistance between the source and the load circuits. The present invention employs an electron discharge device connected in series between a source of potential and a load circuit but the sensing arrangement is such that the discharge device is either totally nonconducting or else conducting at its lowest impedance. In order to produce a well regulated load voltage the discharge device is intermittently turned on and off at a high frequency, the duration of the "on" period in comparison to the "off" period determining the value of voltage at the load circuit. A low-pass filter circuit is employed to eliminate the high frequency variations so that the load circuit receives a steady unidirectional current.

As used throughout the specification and claims, the term "trigger circuit" refers to an amplifier stage comprising two electronic triodes with circuit components so adjusted that the circuit is stable when either triode is conducting and the other triode is non-conducting. Applying an actuating pulse or voltage to such a stage momentarily switches conductivity from one triode to another.

One of the objects of this invention is to provide an improved voltage regulator which avoids one or more of the disadvantages and limitations of prior art arrangements.

Another object of the invention is to provide a voltage regulator which will respond quickly to variations of voltage in the supply line.

Another object of the invention is to provide a voltage regulator which employs a series electron discharge device which operates at maximum efficiency.

Another object of the invention is to provide a voltage regulator circuit and an inverter circuit for transforming direct current of variable voltage into an alternating current having a regulated voltage.

Another object of the invention is to provide a voltage regulator which combines a series electron discharge device with a rectifier which can be used to transform an alternating current of variable voltage into a direct current regulated voltage.

One feature of the invention includes a trigger device

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which supplies the control electrode of a series electron discharge device with a voltage which either causes the discharge device to pass no current at all or to pass the maximum safe allowable current.

For a better understanding of the present invention together with other and further objects thereof, reference is made to the following description taken in connection with the accompanying drawings.

Fig. 1 is a schematic diagram of connections of a voltage regulator for direct current using a diode sensing device and a Schmitt trigger.

Fig. 2 is a graph illustrating the wave forms occurring in the circuit of Fig. 1.

Fig. 3 is a voltage regulator and inverter combined similar to Fig. 1 but delivering alternating current to a load circuit.

Fig. 4 is a voltage regulator circuit having an alternating current source and delivering an alternating current to a load circuit.

Fig. 5 is a graph which shows some of the wave forms which are used in the circuit of Fig. 4.

Fig. 6 is a schematic diagram showing the combination of a voltage regulator and a rectifier circuit which transforms an alternating current of variable voltage into a direct current of constant voltage.

Fig. 7 is a graph showing some of the wave forms employed in the circuit of Fig. 6.

Fig. 8 is a schematic diagram of connections indicating how the invention may be used in connection with an alternating current supply line to control a large amount of power when the variation of the voltage source is not excessive.

Fig. 9 is a schematic diagram of connections of a voltage regulator using a heater for a sensing device and a thermistor as a control element for a multivibrator.

Fig. 10 is a graph showing the output wave from the multivibrator as applied to the control electrode of the electron discharge device.

Fig. 11 illustrates an alternate circuit which may be used instead of the heater and thermistor circuit in Fig. 9.

Fig. 12 is a schematic diagram of connections similar to Fig. 1 but using an unstable trigger device instead of a Schmitt trigger.

Fig. 13 is a graph showing some of the wave forms produced in the circuit of Fig. 12.

Fig. 14 is a schematic diagram of connections showing a combined voltage regulator and rectifier using a stable trigger circuit which is controlled by a shift in phase of one of the series of pulses applied to the trigger circuit.

Fig. 15 is a series of graphs indicating the wave forms used in the circuit of Fig. 14.

Referring now to Figs. 1 and 2 a voltage regulator circuit employing a series controllable discharge device 20 is connected between a pair of input terminals 21, 22 where direct current may be applied and a pair of output terminals 23, 24 where a load using direct current is connected. A Schmitt trigger circuit 25 is arranged to receive the voltage from an alternating current generator 26. A portion of the Schmitt trigger circuit is connected to the controllable discharge device 20 by means of conductor 27. In order to determine the voltage applied to a direct current load a diode type discharge device 28 is connected with its filament across the load terminals 23, 24 but in series with a regulating resistor 30. The anode of the diode receives its polarizing potential from the positive supply terminal 21 in series with a resistor 31. The anode is connected, by means of conductor 32, to the right grid of a double triode 33 in the Schmitt trigger circuit. A low pass filter 34 is connected between discharge device 20 and the output terminals 23, 24 in order to remove the pulse variations from the regulator circuit

and present a constant direct current voltage to the load circuit.

The Schmitt trigger circuit 25 is well known in the electronic art and has been described in detail in the *Journal of Scientific Instruments*, page 24, 1938. The circuit is arranged so that either one of the two triodes in tube 33 may be conducting depending upon the potential of point 35. If the potential at this point is raised above a certain value conduction will be transferred from the left triode to the right triode and if the potential of point 35 is reduced below a similar potential conduction will be transferred from the right triode to the left triode.

As shown in Fig. 1 an alternating current generator 26 is connected between point 35 and the common cathode of the two triodes. This means that once during every positive cycle the Schmitt trigger will be actuated and conductance will shift from the left triode to the right and back again. If the direct current potential of conductor 35 is kept at a low figure the Schmitt trigger circuit will not be actuated until the A. C. generator reaches its maximum value of positive potential. This condition is illustrated in Fig. 2 where the wave 36 represents a positive part of the wave from the generator and the pulse 37 represents the voltage on conductor 27 due to a very short double transfer of conductance in tube 33. If the potential of the anode of diode 28 is now raised the trigger circuit 25 will be actuated by the A. C. generator considerably in advance of the previous condition and also the return of conductance from the right to left side will occur considerably later during the positive part of the wave. The result of this altered condition is a positive pulse 38 which is applied to the control electrode of tube 20 and exists for a much longer time and therefore passes more current to filter circuit 34. The circuit is arranged so that the pulses 37 or 38 apply a voltage to the tube 20 which conditions it for maximum current conduction. When there are no pulses applied to conductor 27 tube 20 presents an infinite resistance to the flow of current. It will be obvious that this type of circuit is a voltage regulator since an increase in voltage at the output terminals 23, 24 produces a larger current through the filamentary cathode of triode 28 thereby lowering its resistance and lowering the potential on conductors 32 and 35. Lowering the voltage on the output terminals produces a reverse effect.

The circuit shown in Fig. 3 is arranged to receive direct current power on its input terminals 21, 22 and to produce alternating current power on output terminals 40, 41. A series controllable discharge device 20 is connected in a manner similar to Fig. 1 and a diode discharge device 28 is employed to sense the voltage on the output terminals. The resistance of this diode determines the potential on Schmitt trigger circuit 25 and applies pulses to conductor 27 in the same manner as was shown and described in Fig. 1. However, a resonant circuit 42 is connected in parallel with the output terminal circuit instead of the low pass filter circuit 34. This produces an alternating current output.

The circuit shown in Fig. 4 is employed to regulate the alternating current voltage which is applied to terminals 43, 44 and to produce an alternating current supply at terminals 40, 41. This circuit is capable of several variations. If a double-pole switch 45 is connected to the right, the Schmitt trigger will receive its triggering voltages directly from the input line. Then, if a resonant circuit such as shown in Fig. 3 is connected across the line, a regulated output will result in the same manner as described in Fig. 3. If the input line varies considerably in voltage an additional alternating current generator 26 may be employed and connected to the Schmitt trigger 25 by throwing switch 45 to the left. This arrangement gives an alternating current output within a small range of voltage values.

The circuit illustrated in Fig. 4 may be easily con-

verted to produce direct current from alternating current by the addition of a rectifier and filter unit 46.

The wave forms shown in Fig. 5 illustrate one phase in the operation of the circuit shown in Fig. 4. Let it be assumed that switch 45 has been connected to the left and generator 26 produces a high frequency as indicated by the wave forms 47. The alternating current applied to terminals 43, 44 has a wave form as indicated by graph 48. Under these conditions if the voltage on conductor 32 is low only one or two positive waves 50 will affect the Schmitt trigger. If the potential of conductor 32 is raised a larger number of pulses 51 will cause the Schmitt trigger to be actuated. This circuit then acts as a frequency changer, changing the low frequency 48 to the high frequency as indicated by the forms 50, 51.

The circuit shown in Fig. 6 uses a Schmitt trigger 25 and a diode 28 in the same manner as described in Figs. 1, 3, and 4. The circuit is designed to receive its power from an alternating current supply and to deliver a regulated direct current. Two rectifier tubes 53 and 54 are employed each having a controllable electrode which receives the positive pulses delivered by the Schmitt trigger 25. Power is applied to the tubes 53, 54 by means of a transformer 55, the end terminals of the transformer secondary being connected to the tube anodes. Load terminals 56, 57 are connected through a filter circuit 58 to the mid-point of the transformer secondary and to the two cathodes. The operation of this circuit may be understood by referring to the wave forms in Fig. 7 where the sine wave 60 represents the input voltage and the voltage applied to each anode. When the diode 28 senses a low voltage on the output terminals it applies a high voltage to the Schmitt trigger and therefore the output pulses from this circuit applied over conductors 61 and 62 will be of long duration as indicated by the wave forms 63. This means that the rectifier tubes 53, 54 will pass half waves of current for considerable time duration, these forms being indicated by 64—64 in Fig. 7. If the diode senses a high voltage on the output terminals the duration of the pulse sent out by circuit 25 will be of short duration as indicated by wave form 65. This results in a pulse-like output wave 66. It should be pointed out that the waves 64 and 66 are the output currents before being filtered by circuit 58, the actual output current as delivered at terminals 56 and 57 will be transformed by the filter circuit and will have a wave form similar to that shown at 60.

It will be obvious from a study of the above described circuits that the regulation is in many cases severe and at times eliminating entirely the presence of an output wave. In order to make the circuit more practical and better suited to commercial application the circuit in Fig. 8 has been devised and comprises a transformer 67 which receives the full voltage from input terminals 43, 44 connected to an alternating current supply line. The secondary 68 of this transformer is connected to the output terminals 40, 41 through another secondary winding 70. The primary winding 71 is connected to the output circuit of a voltage regulator similar to that shown in Fig. 3 having a Schmitt trigger control 25 and a sensing diode 28. The operation of this device should be obvious. A large percentage of the alternating current power passes directly through transformer 67 to the output terminals. A smaller percentage of the power is taken by circuit 72 which contains the series controllable discharge devices and controls this power by circuit 25 in the method described above. The output of circuit 72 is added to the unregulated supply by putting the two secondary windings in series. This form of voltage regulator controls a large amount of power by a device which handles a relatively small amount of power but which must be over-regulated in order to produce a regulated output.

The above described voltage regulators all contain Schmitt triggers for turning the series discharge device on or off. Other types of trigger circuits may be used;

Fig. 9 showing a multivibrator type of circuit and Fig. 12 showing that type of circuit commonly called a flip-flop. This type of circuit is unstable in one triode but stable in the other triode, therefore when an actuating pulse transfers conductance from the stable triode to the unstable triode the conductance will return after a short delay but without the aid of any additional actuation.

Referring now to Fig. 9, input terminals 21, 22 are for connection to a direct current source of supply. A controllable discharge device 20 is in series with the line connected to terminal 21. A filter circuit 34 is connected in the line adjacent to output terminals 23 and 24 similar to the circuit shown in Fig. 1. Discharge device 20 contains a controllable element connected to conductor 27 which is in turn connected to one of the anodes in a double triode tube 74. This tube is connected to a multivibrator circuit 75 which oscillates continually sending out waves which are approximately flat-topped. The duration of the pulses sent out by either one of the two triodes may be varied by varying the resistances between the control electrodes and the common cathode of tube 74. When these resistances are equal a series of equally spaced square-topped waves 76 (Fig. 10) are applied to conductor 27 and the control element of device 20. When the resistance of one element such as 77 is decreased the duration of the wave is decreased as shown by pulses 78 and conversely when the resistance is increased pulses 80 result. The operation of the circuit shown in Fig. 9 will then be obvious when it is understood that the resistance of a thermistor varies greatly with the temperature, increasing in resistance as the temperature is lowered. The sensing device in this circuit is a heater coil 81 which is connected across terminals 23, 24 and varies in temperature in accordance with the voltage applied to the load. When the load voltage rises the temperature of the heater 81 and the thermistor 77 both rise and result in the wave form 78. When the reverse happens, wave form 80 results causing the tube 20 to transmit currents for a longer duration and the terminal voltage at 23, 24 goes up. It is not necessary to control a multivibrator by means of a thermistor. A diode 28 as indicated within the dotted lines in Fig. 11 may be used instead with similar results.

The circuit shown in Fig. 12 employs a flip-flop circuit 83 and has the usual input terminals 21, 22 for connection to a direct current source of supply. Output terminals 23, 24 are for application to a load circuit using direct current. A controllable discharge device 20 and a filter circuit 34 are employed similar to Fig. 1. The sensing device is a diode discharge device 28 having a regulating resistor 30. For this circuit a pulse generator 84 is employed and produces a wave which comprises a series of short volt pulses 85 shown in Fig. 13. These voltage pulses are applied between the common cathode and the right hand control electrode of a double triode tube 86. The left anode of double triode 86 is connected to a voltage divider 87 the midpoint of which is connected through a resistor to conductor 27 and the control elements of discharge device 20.

The action of this circuit is as follows: When the output voltage is the desired value and the system is in equilibrium, the pulse generator 84 actuates circuit 83 causing conductance to shift from the left to the right triodes at each positive cycle. The conductance transfers back to the left side a short time interval later producing a square topped voltage on conductor 27 which is indicated in Fig. 13 by wave form 88. Now, if the voltage of the supply should rise, the voltage across the diode filament will also rise and reduce the resistance of the anode-cathode circuit in the diode, thereby decreasing the time constant of the circuit connected to the left control electrode in tube 86. Under these conditions when the circuit is actuated and conductance shifted to the right side of the tube it will remain there for a shorter time interval than before and produce a voltage wave

form on conductor 27 which is indicated by forms 85 in Fig. 13. This lowers the average current passed by tube 20 and reduces the output voltage to the desired value.

If the output voltage goes down the reverse happens and the transfer of conductance in double triode 86 continues for a longer time interval resulting in pulses 90 as shown in Fig. 13 and permitting more current to pass through discharge device 20 to raise the output voltage to the desired constant value.

The circuit shown in Fig. 14 receives power at input terminals 43, 44 from an alternating source of supply and delivers a direct current output at terminals 23, 24. This circuit employs a transformer 55 similar to the circuit shown in Fig. 6 and it also contains rectifier tubes 53 and 54. The output circuit is connected through a filtering circuit 58, the positive side of the output being connected to both cathodes while the negative output terminal is connected to the mid-point of the secondary winding of transformer 55. A diode sensing tube 28 is employed having a manually regulated resistance unit 30. This regulator circuit employs a stabilized trigger circuit 92, one anode of which is connected by means of conductors 61 and 62 to the control elements of tubes 53 and 54. Stabilized trigger circuits are well known in the electronic art and can be controlled so that a double triode 93 will conduct in either triode for any length of time until the circuit is actuated and conductance transferred to the other triode. Actuation of this circuit is generally done by the application of a negative pulse to the control electrode of the conducting triode.

In order to cause a transfer of conductance from the right triode to the left an actuating circuit is employed which includes a transformer 94, a limiting circuit 95 which contains a battery, and a second limiting circuit 96 which contains only a rectifier unit. The input voltage furnished by secondary winding 97 is a sine wave but circuit 95 limits the negative excursion and results in clipping the negative part of the wave as indicated in Fig. 15 by wave form 98. Circuit 96 short circuits the positive portion of the wave and eliminates it completely. This square top negative wave is then applied through a capacitor 100 which differentiates it and produces the wave form 101 in Fig. 15. The positive portions of this wave produce no result but each negative portion actuates the trigger circuit and transfers conductance to the left side.

A third transformer 102 is connected to a resistor 103 and a saturable reactor 104. The mid-point of the secondary winding is connected to the primary of a fourth transformer 105 the secondary of which is connected to a negative limiter circuit 95A and a positive circuit 96A. This circuit also contains a capacitor 100A and is exactly similar to the actuating circuit described above. The output of this circuit is connected to the control electrode in the left triode of tube 93.

Saturable reactor 104 is controlled by a direct current winding 106 and the current for this winding is derived from an amplifier tube 107. The amplifier tube is supplied with a positive potential which is derived from a rectifier circuit 108 and the input to amplifier tube 107 is derived from diode 28 which acts as a sensing device to determine the voltage on output terminals 23, 24. The positive potential for the operation of diode 28 is derived from a rectifier circuit 113.

The operation of this circuit is as follows: Let it first be assumed that the voltage applied at the input terminals does not vary and the voltage delivered at the load terminals is the desired amount. Then the negative pulses sent over conductor 110 will bear a predetermined phase relationship to the negative pulses sent over conductor 11. This condition results because the anode current through diode 28 is constant as is also the anode current through amplifier tube 107 and direct current winding

106. The ratio of impedance values of reactor 104 to resistor 103 (also capacitor 109 and resistor 119) determines the phase angle of the voltage delivered by the secondary of transformer 105. This phase relationship is indicated in Fig. 15 by the comparative positions of pulses 101 and pulses 112. The negative pulse 101 triggers tube 93 to transfer its conductance and then the pulse 112 is applied to the trigger circuit to transfer the pulse back again. During the transfer period a pulse 114 is sent over conductors 61 and 62 to condition tubes 53 and 54 to conduct.

Now let it be assumed that the voltage on the output terminals rises, thereby increasing the temperature of the filament of diode 28 lowering the anode resistance and reducing the potential of the control electrode of amplifier tube 107. This reduces the direct current through winding 106 and increases the inductance of winding 104 thereby changing the phase of the pulse sent over conductor 110 and shortening the duration of pulse 114 applied to the rectifier tubes thereby reducing the current through the tubes and causing a reduction of the output voltage at terminals 23, 24.

While there have been described and illustrated specific embodiments of the invention, it will be obvious that various changes and modifications can be made without departing from the spirit of the invention which should only be limited by the scope of the appended claims.

I claim:

1. A voltage regulator for delivering a constant voltage at a pair of load terminals when the regulator input terminals are connected to a supply of direct current which may vary in voltage comprising; an electronic discharge device including, a cathode, an anode, and a control electrode; said discharge device connected in series between the supply and load terminals; a voltage sensitive circuit including a diode having a filamentary cathode coupled to said load terminals; a trigger circuit coupled to said diode and including a double triode which generates a series of pulses, the width of which is proportional to the load terminal voltage; an alternating

current source connected to the trigger circuit for cyclicly conditioning the trigger circuit for actuation by the voltage sensitive circuit; and circuit means which connects the trigger circuit to the control electrode of said electronic discharge device.

2. A voltage regulator for delivering a constant voltage at a pair of load terminals when the regulator input terminals are connected to a supply of direct current which may vary in voltage comprising; an electronic discharge device including a cathode, an anode, and a control electrode; said discharge device connected in series between the supply and load terminals; a voltage sensitive circuit including a diode having an anode and a filamentary cathode coupled to said load terminals; said diode arranged to vary its anode current when the load voltage is varied; a trigger circuit coupled to said diode anode and including a double triode which generates a series of pulses, the width of which is proportional to the load terminal voltage; an alternating current source connected to the trigger circuit for cyclicly conditioning the trigger circuit for actuation by the voltage sensitive circuit; and circuit means which connects the trigger circuit to the control electrode of said electronic discharge device.

3. A voltage regulator as set forth in claim 2 wherein said trigger circuit is arranged to deliver an output voltage to the control electrode of said electron discharge device which varies abruptly between a maximum and a minimum value and causes the discharge device to intermittently present a maximum impedance and a minimum impedance to the current flowing through it.

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