

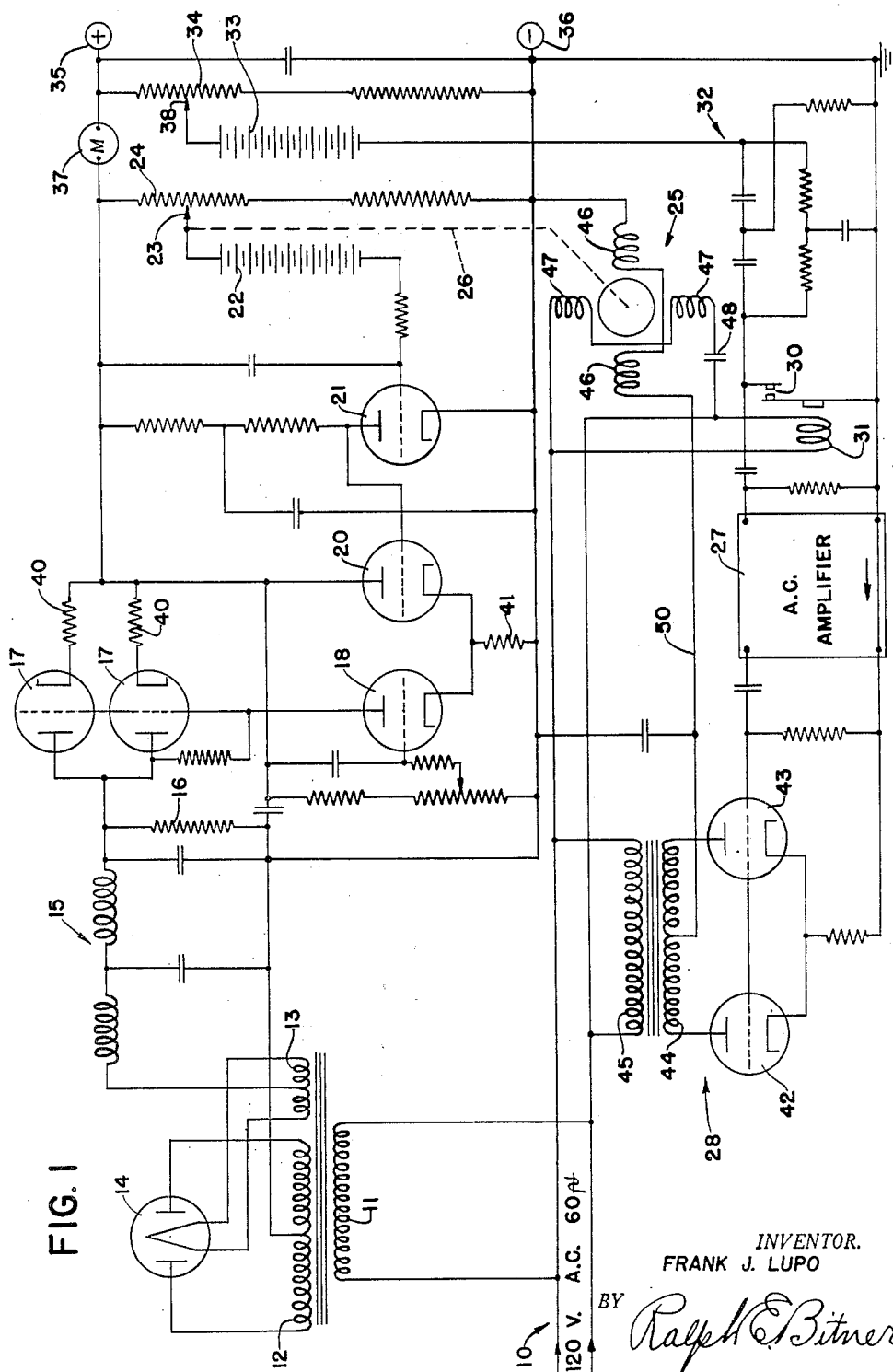
Jan. 13, 1953

F. J. LUPO
VOLTAGE REGULATOR

2,625,675

Filed March 16, 1951

2 SHEETS--SHEET 1



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2 SHEETS—SHEET 2

FIG. 2

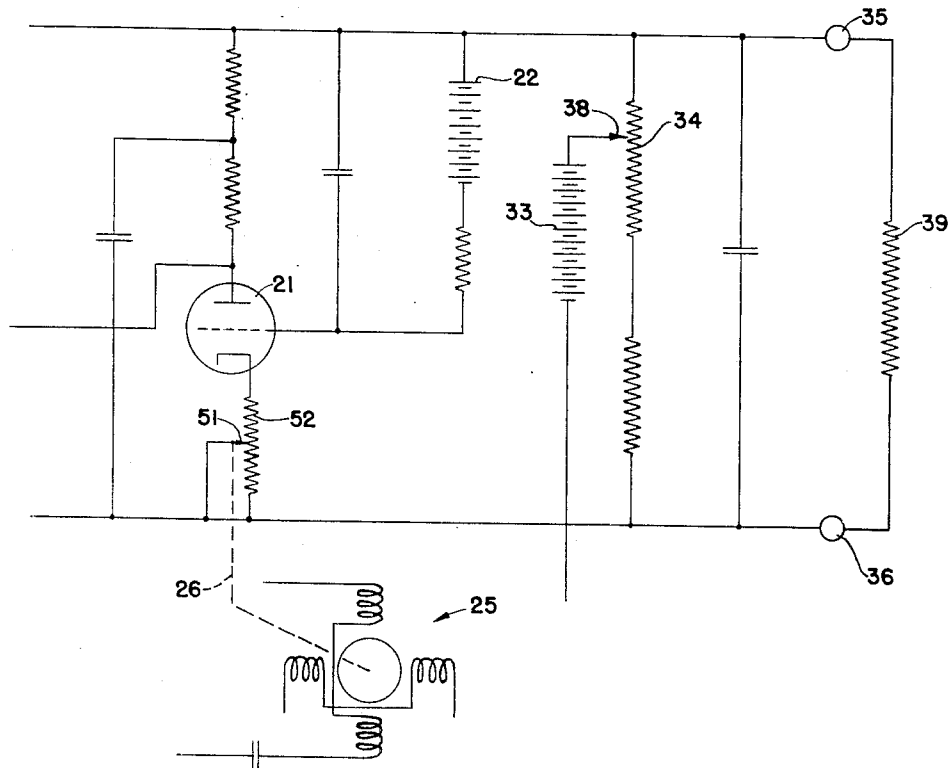


FIG. 3

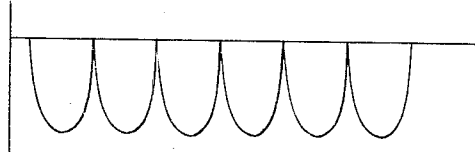
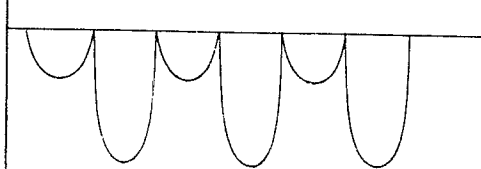


FIG. 4



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VOLTAGE REGULATOR

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7 Claims. (Cl. 323—4)

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This invention relates to voltage regulators of the type which receive power from an alternating current source and deliver direct current to a load circuit. The invention has particular reference to voltage regulators capable of delivering a voltage which is constant to one part in 600,000 with respect to a reference voltage source which is used as a standard.

Electronic regulator circuits are old in the art and many different circuits have been proposed and used. The most popular arrangements generally employ one or more triode discharge devices in series connection between the supply line and the load with a voltage sensitive circuit coupled between the load and control electrode of the series tube. The voltage sensitive circuit may use a battery or a gaseous discharge tube as a reference voltage. Such circuits regulate quite well, especially those using a battery as a reference voltage. When properly adjusted these circuits provide a compensation for voltage variations of the power source and also for variations of the load impedance.

Prior art regulators, however, have not been designed to give perfect regulation and there has always existed a small variation in the load voltage when the supply voltage varies by several percent. The greatest defect of prior art regulators is the slow drift in load voltage which occurs over a period of several minutes or hours, and which is caused by ambient temperature changes and variations in contact potential in the voltage sensitive part of the circuit.

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 deliver a constant unvarying potential to a load circuit using a controlled variable tap on a voltage divider to compensate and correct for the slow drift caused by variable characteristics in the voltage sensitive circuit.

Another object of the invention is to improve the voltage regulation in electronic regulator circuits so that a variation of ten percent in the supply voltage will cause the load voltage to vary less than one part in 600,000.

Still another object of the invention is to improve the voltage regulation in the presence of abrupt variations in load impedance and low frequency variations in load current, thereby greatly reducing the effective internal impedance (as measured at the output terminals) of the power supply. Impedances of less than an ohm are easily obtainable.

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The invention includes an electron discharge device in series arrangement between the source and the load. The bias potential of the control electrode of the discharge device is derived from the output of a three stage direct current amplifier. The input of this amplifier is connected to the variable contact of a voltage divider which in turn is connected to the load terminals. A novel feature of the invention comprises a voltage sensitive circuit for detecting an error voltage, a reference battery, an inverter system for converting the error voltage to alternating current, an amplifier and phase discriminator, and a reversible motor which is coupled to the variable contact on the voltage divider to return the system to equilibrium and reduce the error voltage to zero.

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 showing a circuit of a voltage regulator.

Fig. 2 is a schematic diagram of connections of a part of a voltage regulator showing an alternate arrangement for connecting the input circuit of the direct current amplifier.

Fig. 3 is a curve showing the current wave shape obtainable at the mid-point of the transformer which supplies the anode power in the phase discriminator stage when the input to that stage is zero.

Fig. 4 is a curve similar to Fig. 3 but showing the current wave shape when the input is other than zero.

Referring now to the drawing, power lines 10 are connected to the usual 60 cycle commercial supply. A primary 11 of an iron-cored transformer is connected across the power lines and secondaries 12 and 13 supply power to the anodes and filament of a rectifier tube 14. A pulsating voltage is obtained between the mid-points of the two secondaries and a filter 15 is employed to eliminate the alternating components and deliver direct current power across a terminal resistor 16.

One or more electron tubes 17 are connected in series with the positive power conductor and constitute the means for regulating the load voltage. The control electrodes of the series tubes 17 are connected to the anode of an amplifier tube 18 and the cathodes of the series tubes are connected to the anode of a second amplifier tube 20. Amplifier tubes 18 and 20 are part of a direct current amplifier system which includes a third

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tube 21 and an input circuit comprising a bias battery 22 and a movable contact point 23 which is part of a voltage divider 24.

The movable contact point 23 is controlled by a reversible motor 25 through a mechanical linkage 26. The reversible motor receives its power from an A. C. amplifier 27 and a phase discriminating stage 28. The input to these amplifier stages comes from an inverter circuit which includes a set of contacts 30 driven by a coil 31 which is connected across the power lines 10. The inverter circuit also includes a filter circuit 32, a voltage reference battery 33, and a voltage divider 34 which is connected across the load terminals 35, 36. An ammeter 37 may be included in the circuit.

The operation of the circuit is as follows: Let it first be assumed that the circuit is balanced, the input voltage is constant, and the output impedance does not vary. Under these conditions all the voltages are stabilized and the motor armature does not turn. The voltage drop from the contact point 38 to ground is equal to the voltage of the reference battery 33. Since these voltages are equal, there is no tendency for current to flow between the contact points 30 when they are made, and as a result the input to amplifier 27 is zero and the control electrodes of the tubes in stage 28 receive no added voltage.

In the balanced condition the voltage drop between contact point 23 and ground is substantially equal to the voltage of battery 22 and triode tubes 21, 20 and 18 all pass a steady average current between their anodes and cathodes.

Now let it be assumed that the voltage of the supply lines 10 is increased by ten percent of the normal value. This action causes the voltage across resistor 16 to be increased a like amount and the potential of the anodes of triodes 17 has a tendency to increase and send more current through the triode anodes. However, the anodes are connected, through a high resistor, to the anode of triode 18 and the control electrodes of triodes 17. The control electrode of triode 18 is connected to a voltage divider which is connected across the load terminals and, therefore, the increase in supply voltage tends to increase the potential of this electrode. The increase in potential tends to increase the flow of current through the anode of triode 18 and reduce the potential of the control electrodes of triodes 18, thereby lowering the current through the series triodes and lowering the voltage across the load circuit.

From the above analysis it will be evident that triode 18 has a regulating action all its own without using a voltage reference or standard. The amount of regulation available, however, is not sufficient to produce accurate results unless supplemented by other and more refined circuit elements.

An increase in potential on the supply lines 10 tends to increase the voltage drop across divider 24 and hence add to the voltage of bias battery 22 and raise the potential of the control electrode of amplifier triode 21. This increase in voltage is transmitted through the amplifier stages by a decrease of potential of the control electrode of triode 20 and an increase of potential of the control electrode of triode 18. The result of the amplifier action is a decrease of the potential of the control electrodes of series triodes 17 and a consequent lowering of the voltage to the original steady state value at the load terminals 35, 36.

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The anode-cathode current of triode 20 passes through resistor 41 which is common to triode 18 and, therefore, a change in this current is applied to the potential difference between the cathode and control electrode of triode 18.

The above described circuit (omitting voltage divider 34 and associated circuits) functions as an accurate voltage regulator and if the circuit constants associated with the direct current amplifier remained constant over a long interval of time the circuit would no doubt be satisfactory for most classes of voltage supply.

It is well known that direct current amplifiers are subject to a variety of circuit variations which alter the overall gain and in the present application produce erroneous results. Changes in contact potential, changes in resistance due to ambient temperature changes, and changes in operating tube characteristics all produce a varying anode-cathode current in the output triode 18. These changes occur at a very slow rate and produce a gradual drift in output current rather than an abrupt change.

To compensate for the above mentioned gradual drift in output current the additional control means is added to the circuit. Its operation may be described as follows: When the characteristics of the direct current amplifier changes to produce a different voltage across the load terminals 35, 36, the condition is sensed by the circuit combination which includes voltage divider 34, battery 33, and contacts 30. When the voltage drop between contact point 38 and ground differs from the voltage of battery 33, a voltage difference is produced across open contacts 30, and when the contacts are made a current pulse is produced which is applied to the input terminals of A. C. amplifier 27. The filter 32 prevents the pulse from travelling back to the load terminals 35, 36. The filter also prevents unwanted alternating components from entering the A. C. amplifier.

The output of amplifier 27 is applied to the control electrodes of a pair of power triodes 42 and 43, the anodes of which are connected to the opposite ends of a secondary transformer winding 44. The primary winding 45, coil 31, and windings 46 of motor 25 are all connected to the alternating power lines 10 and all receive the same frequency. During normal operation when the system is balanced no alternating voltage is impressed on the control electrodes of tubes 42, 43 and the current pulses through the tubes are equal.

The anode of one triode is positive when the other anode is negative and as a result each triode conducts only during alternate halves of the cycle. With no signal applied to the control electrodes, the combined anode currents in conductor 50 produce a wave as shown in Fig. 3, having a frequency of 120 cycles per second, similar to the output of a full wave rectifier.

If the pulses are equal, no 60 cycle component appears in the output. However, when a 60 cycle signal from amplifier 27 is applied to the control electrodes of triodes 42, 43, the pulses through one triode are increased while the pulses through the other triode are decreased, thereby creating a 60 cycle component in conductor 50 as indicated by the curve shown in Fig. 4. Depending upon the phase of the signal applied to the control electrode, the 60 cycle component is either in or out of phase with the line voltage. Since the direction of rotation of motor 25 is determined by the phase relationship between the

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currents in windings 46 and 47, the phase of the 60 cycle component in the output signal from amplifier 27 controls the direction of motor rotation. Windings 47 are the usual split phase windings in series with a large capacitor 48; they are permanently connected to power lines 10 and always carry current.

The motor windings and the transformer windings are connected so as to move contact point 23 (by means of mechanical coupling 26) toward the ground end of the voltage divider 24 whenever a change in the amplifier characteristics produces too high a line voltage at the load terminals. When the load voltage drifts toward a lower value, contact point 23 is moved toward the negative end of the voltage divider.

The partial circuit shown in Fig. 2 is an alternate connection which may be employed to obtain the same result. In this circuit battery 22 is connected permanently to the positive line conductor. Connections for the reference battery 33 and the voltage divider 34 are the same as shown in Fig. 1. However, the compensating effect, caused by motor 25 and delivered through the mechanical linkage 26, is applied to a contact point 51 on a resistor 52 which is inserted in the cathode line of triode 21. It is obvious that a change in resistance value in resistor 52 produces a change in the control electrode potential of triode 21 in the same manner as a shift in contact point 23 on voltage divider 24. In all other ways the circuits indicated by Figs. 1 and 2 are identical and function in the same manner to deliver a constant voltage to load 39.

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

What is claimed is:

1. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit, a voltage sensitive circuit connected across the load circuit for sensing a variation of load voltage, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to a control electrode in the series electron discharge device, an inverter for converting said voltage variations into a series of pulses, an electric motor with a mechanical connecting means for altering the characteristic of the direct current amplifier, and an alternating current amplifier with its input connected to the inverter and its output connected to the motor for amplifying the series of pulses and applying the amplified power to the motor to change the direct current amplifier characteristic.

2. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit and having a control electrode for varying the series impedance, a voltage sensitive circuit connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter for

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converting said voltage variations into a series of pulses, a motor with a mechanical connecting means for altering the characteristic of the direct current amplifier, and an alternating current amplifier with its input connected to the inverter and its output connected to the motor for amplifying the series of pulses and applying the amplified power to the motor to change the direct current amplifier characteristic.

3. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source of a load circuit and having a control electrode for varying the series impedance, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter for converting said voltage variations into a series of pulses, a motor with a mechanical connecting means for altering the characteristic of the direct current amplifier, and an alternating current amplifier with its input connected to the inverter and its output connected to the motor for amplifying the series of pulses and applying the amplified power to the motor to change the direct current amplifier characteristic.

4. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit and having a control electrode for varying the series impedance, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter including vibrating contacts controlled by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, a motor with a mechanical connecting means for altering the gain characteristic of the direct current amplifier, and an alternating current amplifier with its input connected to the inverter and its output connected to the motor for amplifying the series of pulses and applying the amplified power to the motor to change the gain of the direct current amplifier.

5. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit and having a control electrode for varying the series impedance, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter including vibrating contacts controlled by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends

upon the polarity of the variation of load voltage, a two-phase motor having a first set of coils connected to the alternating current supply and having a mechanical connecting means for changing the output amplitude of the direct current amplifier, and an alternating current amplifier with its input connected to the inverter and its output connected to a second of coils in the two-phase motor for amplifying the series of pulses and applying the amplified power to the motor to change the output amplitude of the direct current amplifier.

6. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit and having a control electrode for varying the series impedance, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter including vibrating contacts controlled by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, a two-phase motor having a first set of coils connected to the alternating current supply and having a mechanical connecting means for changing the output amplitude of the direct current amplifier, and an alternating current amplifier and phase discriminator with its input connected to the inverter and its output connected to a second set of coils in the two-phase motor for amplifying the series of pulses in their proper phase relation and applying the amplified power to the motor to change the output amplitude of the direct current amplifier and thereby eliminate the variation of load voltage.

7. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit and having a control electrode for varying the series impedance, a first voltage sensitive circuit includ-

ing a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a voltage value, a second voltage sensitive circuit also including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier with its input circuit connected to said first voltage sensitive circuit and with its output circuit connected to the control electrode in the series electron discharge device, an inverter connected to the second voltage sensitive circuit and including vibrating contacts controlled and operated by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, a two-phase motor having a first set of coils connected to the alternating current supply and having a mechanical connecting means for changing the output amplitude of the direct current amplifier, and an alternating current amplifier and discriminator with its input connected to the inverter and its output connected to a second set of coils in the two-phase motor for amplifying the series of pulses in their proper phase relation and applying the amplified power to the motor to change the output amplitude of the direct current amplifier and thereby eliminate the variation of load voltage as sensed by the second voltage sensitive circuit.

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