Dec. 27, 1966 A. R. PERRINS 3,295,053

AUTOMATIC VOLTAGE REGULATOR

Filed Sept. 13, 1963 3 Sheets-Sheet 1

Fig. 1

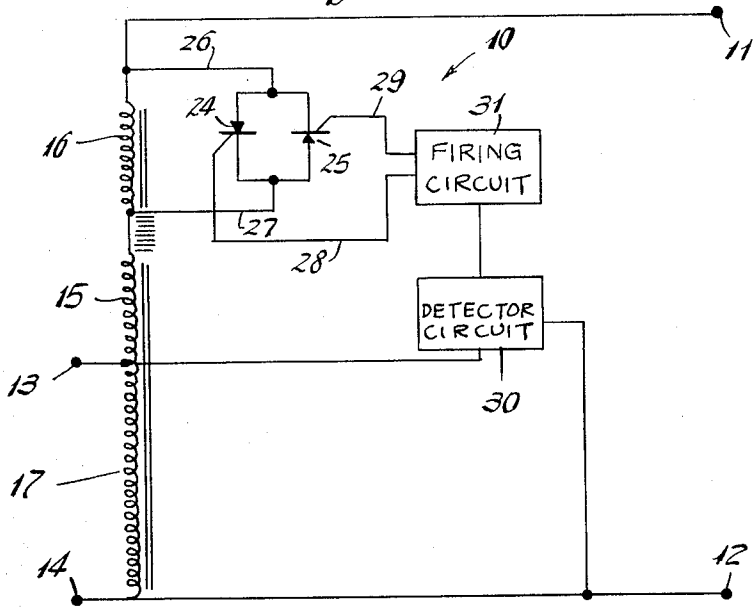
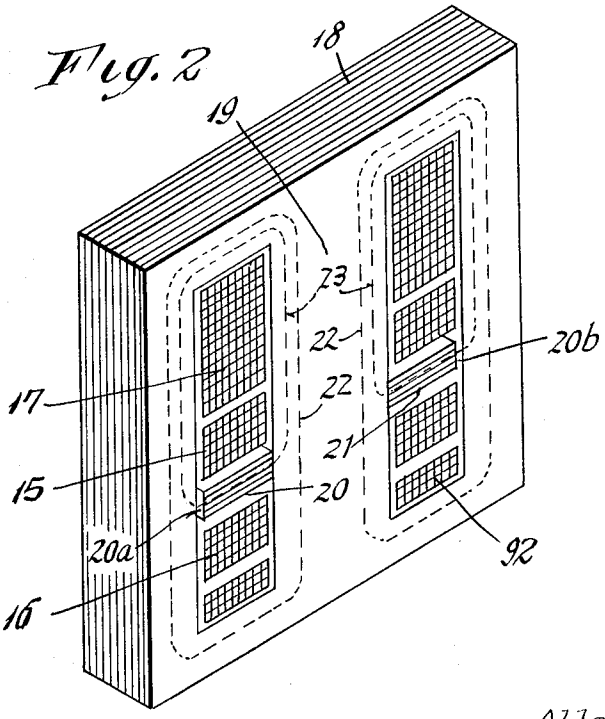


Fig. 2



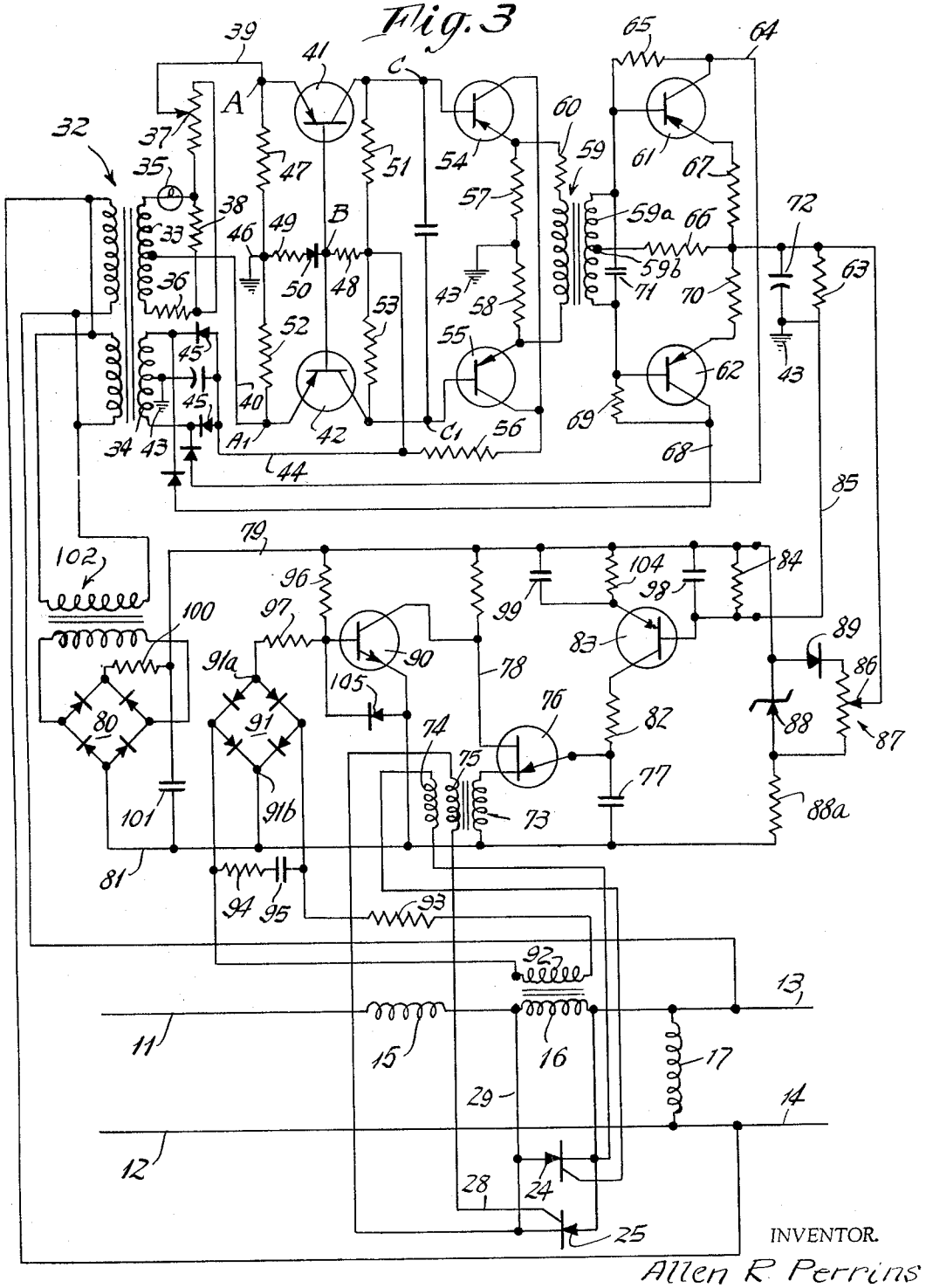
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Fig. 3



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Fig. 5

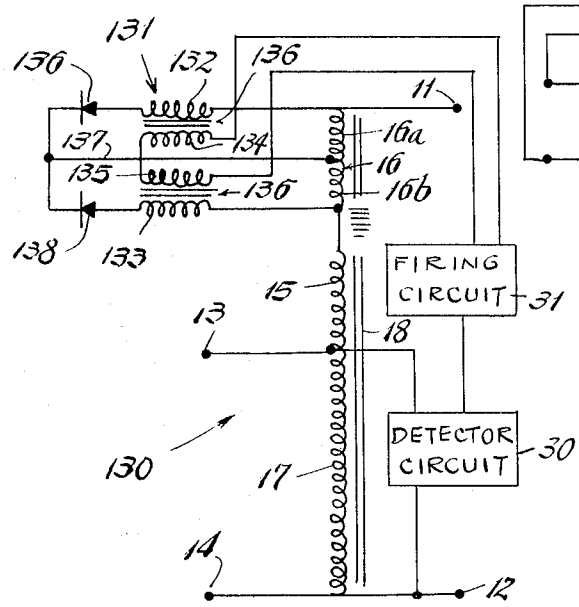


Fig. 4

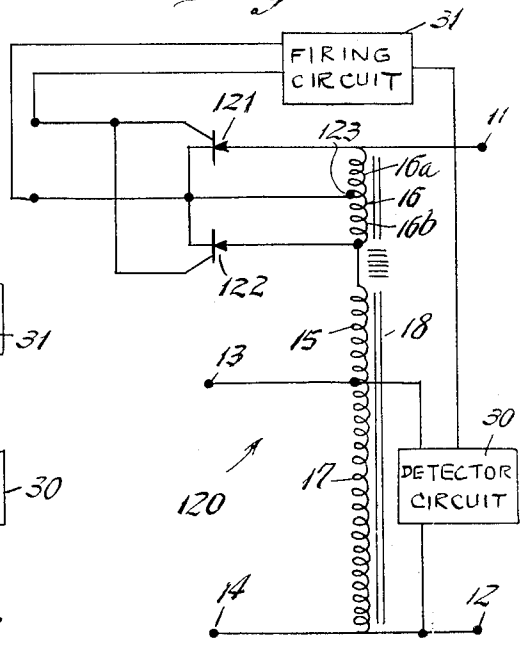
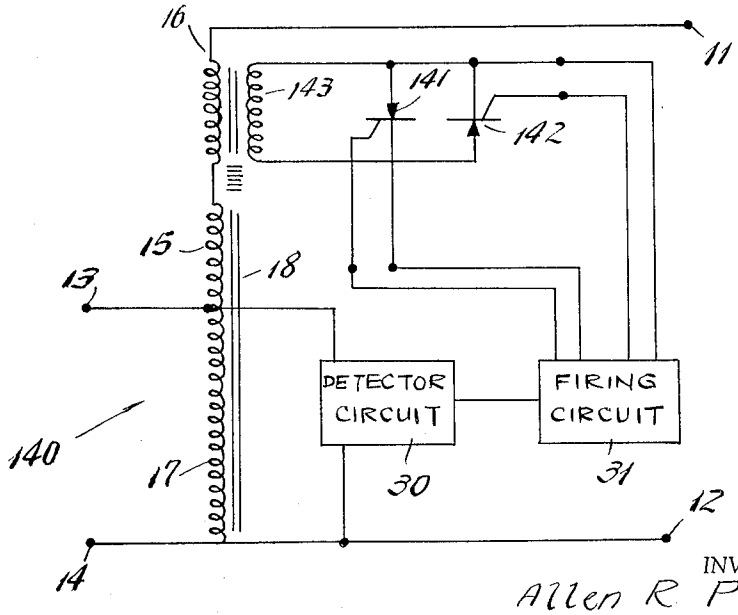


Fig. 6



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3,295,053

AUTOMATIC VOLTAGE REGULATOR

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Filed Sept. 13, 1963, Ser. No. 308,745
13 Claims. (Cl. 323—22)

The present invention relates to an electrical device that is connectible to a source of alternating current to provide a substantially constant output voltage and more particularly to such a device which continually senses any deviation in the output voltage from a desired value and automatically responds to eliminate the deviation.

While there are many types of automatic voltage regulators, they may be generally grouped by the manner in which a change is made to provide the regulation of the output voltage. Thus there is a mechanical type that generally has a moving part, an electronic type in which the conductance of electron valves is controlled and a magnetic type in which inductive flux is varied. The instant invention relates to the latter type and such a device may include a magnetic core which has a flux path with a main winding providing a flux in the path. Additional windings are inductively associated with the flux path to have voltage induced therein by the flux produced by the main winding. One of these windings is an adding winding which acts to increase the value of the output voltage and another is a bucking winding which acts to decrease the value of the output voltage. By changing the linkage of the flux in the main core with these additional windings, variations may be made in the value of the voltages induced in these windings to thereby maintain the output voltage at a substantially constant value.

It is accordingly an object of the present invention to provide an automatic voltage regulator of the magnetic type and which, for the amount of power which it is capable of regulating, is substantially compact, electrically efficient and lightweight.

Another object of the present invention is to provide an automatic voltage regulator of the above type that has a rapid response to correcting a deviation in the output voltage from the desired value by reason of it assuming the same initial condition for every half cycle of alternating current input voltage in preparation for correcting any deviation.

A further object of the present invention is to provide an automatic voltage regulator that achieves the above advantages, that is relatively economical to manufacture, requires only low power for correcting deviations and which is extremely durable and reliable by reason of using only static elements.

In the automatic voltage regulator of the present invention, there is provided a magnetic core which has at least one leg on which is wound to be in inductive association therewith a main winding that is connected to be excited by an alternating current voltage and thus provides a changing magnetic flux in the leg. Also wound on the leg is an adding winding in which a voltage is induced and the adding winding is connected to have its induced voltage added to the alternating current voltage. In addition, the one leg further has inductively associated therewith a bucking winding in which a voltage is also induced by the flux in the common leg but this voltage is made to be subtracted from the alternating current voltage. Thus the adding winding serves to increase the output voltage while the bucking winding acts to decrease the output voltage. The voltage induced in the bucking winding is varied by changing the amount of flux in the portion of the leg with which the bucking winding is associated to effect the substantially constant value of output voltage.

The core further includes in conjunction with the common leg another magnetic path for the flux produced by the main winding with the adding winding being inductively associated with this another path while the bucking winding is not and hence any flux in this path fails to induce a voltage in the bucking winding. The flux that appears in the other magnetic path is varied, according to the present invention, by changing the reluctance of the portion of the common leg that is inductively associated with the bucking winding. This is achieved by, in effect, short-circuiting the bucking winding so that it functions as a short-circuited turn and hence opposes any change in flux in that portion of the leg associated therewith. Accordingly, by operation of means for short-circuiting at a selected time during each half cycle the value of the bucking voltage that is induced in the bucking winding may be accordingly controlled thereby to provide maintenance of the substantially constant output voltage.

The short-circuit means in the embodiments of the invention hereinafter described, are made to be inoperative at the beginning of every half cycle of the alternating current to permit the flux to induce a voltage in the bucking winding. However, by the use of a detection circuit that senses the value of output voltage and compares it to its preselected value, the short-circuiting means becomes effective, if needed, at an intermediate point in each half cycle to effect the short-circuiting of the bucking winding for decreasing the value of the bucking voltage.

Other features and advantages will hereinafter appear.

In the drawing:

FIGURE 1 is an electrical schematic diagram partly in block form of the automatic voltage regulator of the present invention.

FIG. 2 is a diagrammatic representation of the core and windings of the regulator.

FIG. 3 is an electrical schematic diagram of the regulator.

FIG. 4 is an electrical schematic diagram partly in block form of another embodiment of the present invention.

FIG. 5 is an electrical schematic diagram partly in block form of a further embodiment of the present invention.

FIG. 6 is an electrical schematic diagram partly in block form of a still further embodiment of the present invention.

Referring to the drawing, in the embodiment shown in FIGS. 1–3 inclusive, the automatic voltage regulator is generally indicated by the reference numeral **10** and includes a pair of input terminals **11** and **12** which are adapted to be connected to a source of alternating current. The regulator further includes output terminals **13** and **14** at which the substantially constant output voltage appears, the regulator acting to prevent changes in the value thereof. It will be noted that the terminals **12** and **14** are connected to be common while between the terminals **11** and **13** there is placed in series an adding winding **15** and a bucking winding **16**. In addition, connected across the output terminals is a main winding **17**.

The windings **15**, **16** and **17** are mounted on a closed magnetic core **18** (FIG. 2) that is preferably formed of flat, thin laminations of magnetic iron having the shape shown and thus may be economically composed of E and I sections, as is well understood by those skilled in the art. The core **18** has a common leg, generally indicated by the reference numeral **19**, with which the main winding **17** is inductively associated as are the windings **15** and **16**. However, between the windings **15** and **16** there is positioned on the common leg, an extension on either

side 20 and 21, each of which provides an air gap 20*a* and 20*b*.

With this structure, magnetic flux induced by the main winding in the common leg 19 may traverse the paths indicated by the dotted lines 22. In addition, there are alternate paths which the flux induced by the main winding may traverse, indicated by the dotted lines 23, with the alternate paths being through the section 20 and air gap 20*a* in one instance and section 21 and air gap 20*b* in the other instance. With respect to the flux paths 22, it will be appreciated that effectively all the flux produced by the main winding 17 is linked with the adding winding 15 and this winding is connected so that the voltage induced therein is added to the input voltage that appears at the terminals 11 and 12. The bucking winding 16 however is connected to have the voltage induced therein, by flux traversing the paths 22, to be in opposition to the input voltage and thus be subtracted therefrom. With flux traversing the paths 23, an adding voltage is induced in the adding winding 15, but the bucking winding, by reason of it not being inductively associated with the paths 23, fails to have a bucking voltage induced therein. Thus by varying the flux traversing the paths 22 and 23, the inclusion of the bucking voltage may be changed to maintain the output voltage substantially constant.

In accordance with the present invention, there is provided short-circuited means which performs the function of controlling the division of flux between the paths 22 and 23 and also in the embodiment shown in FIG. 1 provides a bypass or shunt path for the current controlled by the regulator 10. As shown in FIG. 1, the short-circuiting means includes a pair of electronic conductance elements, specifically silicon controlled rectifiers 24 and 25 (SCR) reversely connected in parallel to a lead 26 connected to one side of the bucking winding 16 and by a lead 27 to the other side of the bucking winding. The SCR's 24 and 25 have gate leads 28 and 29 respectively connected thereto so that when a signal voltage appears on the gate leads the SCR's will conduct for the remaining duration of the half cycle. In the absence of a signal, the SCR's are not conducting and in this condition flux traverses the paths 22 inducing both an adding voltage and a bucking voltage to the input voltage to produce the output voltage. Preferably though the invention is not to be considered as limited thereto, the adding voltage is on the order of 10% while the bucking voltage is higher and may be 20% of the output voltage. Accordingly, if the input voltage is higher than that value which the output voltage is desired to have, the SCR's 24 and 25 are maintained in a state of nonconduction with the bucking voltage reducing the input voltage by 20%, the adding winding increasing the voltage by 10% with the consequence that the output voltage is accordingly reduced by the sum of the two voltages, namely 10%.

If on the other hand, the input voltage is lower than the desired value of output voltage, the SCR's are rendered conducting to cause substantially a short-circuit across the bucking voltage winding which by reason of the short-circuit turn effect forces the flux to traverse the paths 23. No voltage is then induced in the bucking winding and as the adding winding increases the input voltage by 10%, the output voltage is thus 10% higher than the input voltage. While windings 15 and 16 have been described as producing adding and bucking voltages respectively, if desired, their functions may be interchanged without departing from the scope of the present invention.

The two conditions of operation of the SCR's 24 and 25, namely conduction or nonconduction, are according to the present invention made to occur within each respective half cycle of the alternating current. Thus the output voltage for each half cycle is the combination of the separate values when the SCR's are conducting and nonconducting. A detector circuit 30 for sensing the value of output voltage and producing a signal to a firing circuit 31 which controls through the leads 28 and 29 the conduction of the semiconductor elements 24 and 25, is provided. For each half cycle of input voltage, the SCR's 24 and 25 are nonconducting for substantially the initial portion of the half cycle and remain so until the detector circuit 30 produces a signal through the circuit 31 to cause the conduction of one or the other, depending upon whether the half cycle is the positive or negative half of the cycle. When an SCR conducts, the effect of the bucking winding is substantially reduced by reason of the flux paths being changed from the path 22 to the path 23 and thus the bucking winding stops introducing a bucking voltage in opposition to the input voltage. It will be appreciated that upon conduction of either SCR 24 or 25 that the bucking winding has a short-circuit path therefor which produces a short-circuited turn effect on the common leg 19. Such an effect acts to opposite a change in flux through that portion of the core inductively associated with the bucking winding and thus as there is no change in flux no voltage is induced in the bucking winding. Moreover, it will be appreciated that a complete path for the flux either through paths 22 or 23 is assured so that the adding winding always has a voltage induced therein.

Referring to FIG. 3, there is shown an electrical schematic diagram of the regulator of the present invention and the parts heretofore referred to have been indicated by the same reference character. Thus there are input terminals 11 and 12 and output terminals 13 and 14, with the main winding 17 being placed in shunt thereacross. In series between the terminals 11 and 13 are the adding winding 15 and bucking winding 16 together with the semiconductor elements 24 and 25. The detector circuit 30 includes a transformer 32 having its primary winding connected to the output terminals and having two center tapped secondary windings 33 and 34. The winding 34 provides a direct current power voltage for the circuit as will be hereinafter explained, while the winding 33 constitutes a pair of adjacent legs in a sensing bridge with the other legs including a non-linear voltage sensitive resistance 35 (such as a tungsten filament lamp) and a linear resistor 36. Connected between resistances 35 and 36 in parallel to each other is an adjustable resistor 37 and a linear resistor 38. Resistance 37 is connected to permit setting the bridge to be balanced, i.e. produce a signal of substantially zero magnitude at a value of output voltage which as will be hereinafter understood is slightly different than the value of the output voltage desired to be maintained constant. The output of the sensing bridge, which is an A.C. signal, indicates the deviation of the output voltage from the value set by the resistor 37 by its magnitude and its direction of the deviation by its polarity with respect to the output voltage of the regulator, and the output signal appears across a lead 39 connected to the adjustable resistance 37 and a lead 40 connected to the center tap of the winding 33. This signal is fed to a pair of transistors 41 and 42 which are connected to amplify the signal, particularly to increase the voltage thereof.

For providing a voltage for the circuit the winding 34 is center tapped and connected to a ground 43 which becomes the positive side since the transistors employed in the herein disclosed embodiment of the invention are PNP types, though if NPN types were employed, the polarity must be reversed. The negative side of the power supply is the lead 44 in view of the direction of the rectifiers 45 which provide full-wave rectification. To provide the bias on the emitter-base circuit of the transistor 41, a lead 46 is connected to the plus ground 43 through a resistor 47 to the emitter while the base is connected to the lead 46 through a resistor 49 and a diode 50 and hence the emitter-base bias voltage is the difference between the voltage drop across the resistance 47 and the drop across the resistance 49 and diode 50, the latter being the larger to make the base negative with

respect to the emitter. The value of bias voltage is sufficient to bias the transistor 41 into its linear operating range.

The transistor 41 is connected to have its output appear as a voltage across a resistance 51 as a result of current flow through its collector-emitter output circuit of transistor 41, resistance 51, lead 44, diodes 45, winding 33, lead 46 and resistance 47. It will be appreciated that when a signal appears at the point A and of a positive polarity from the sensing bridge that the transistor 41 will amplify the signal by increasing the current in the collector-emitter circuit, with the voltage across the resistance 51 being increased.

The transistor 42 is connected in a manner identical to transistor 41, employing common resistor 49 and diode 50 in its emitter-base circuit while a resistance 52 identical to resistance 47 is also present while the collector-emitter circuit has a resistor 53 identical to resistor 51 therein. The collector-emitter circuit of transistor 42 is rendered more conducting when a positive voltage appears in the line 40. Thus the transistors 41 and 42 act as class A push pull amplifiers and serve to amplify the A.C. signal from the sensing bridge.

The amplified signal from the transistors 41 and 42 appears as a potential of varying magnitude between the points C and C′ which is then amplified, particularly current amplified by a pair of transistors 54 and 55 respectively connected as push pull emitter-followers. The base of the transistor 54 is connected to the point C while its collector is connected through a resistance 56 to the negative lead 44. The positive lead 46 is connected to the emitter of the transistor 54 through a resistance 57. The transistor 55 is connected in an identical manner employing a resistance 58 identical to resistance 57 with the resistance 56 being common to collector circuits of both transistors. The primary winding of an isolation transformer 59 is connected between the emitters of the transistors 54 and 55 with resistors 60 in series therewith and is also connected in parallel to resistances 57 and 58 so that the signal amplified by the transistors 54 and 55 appears as a voltage across the winding.

The above elements operate so that as the voltage at C varies by reason of the current flow in the collector circuit of transistor 41, the current through the emitter circuit of transistor 54 will also vary and because the bias on the transistor is sufficient to operate it in its linear range, the voltage appearing across the resistor 57 (and hence the transformer 59) will vary substantially linearly with the voltage appearing at the point C. Similarly for the polarity of signal amplified by the transistor 42, the potential at the point C′ varies, producing a potential change across the resistor 58 (even though the transistors 54 and 55 are primarily connected to be current amplifiers) and both potentials appear across a center tapped secondary winding 59*a* of the transformer 59.

It will be appreciated that the signal appearing in the secondary winding is A.C. and may be of the same or opposite polarity with respect to the voltage at the output terminals 13 and 14 depending upon the direction of the deviation of the output voltage from its selected value.

The secondary winding 59*a* constitutes the input to an amplifying discriminating circuit that includes transistors 61 and 62 with the output of the circuit appearing in effect as a potential across a resistance 63. The transistor 61 has its collector connected to one negative supply lead 64 with a resistance 65 interposed between the collector and the base. The emitter of transistor 61 through resistances 66 and 67 is connected to the center tap 59*b* of the winding with the end of the winding being connected to the base. The transistor 62 similarly has its collector connected to another negative lead 68 of the bias supply 34 with a resistance 69 interposed between the collector and the base. Resistances 66 and 70 are connected between the center tap 59*b* and the emitter of transistor 62 while the base is connected to the other end of the winding 59*b*. A capacitor 71 is connected across the ends of the winding, while another capacitor 72 is connected between the positive ground 43 and the junction of the resistances 67 and 70 to parallel the resistance 63 which is similarly connected.

The transistors 61 and 62 are preferably biased into a state of continuous conduction by the resistances 65 and 67 for the transistors 61 and resistances 69 and 70 for the transistor 62 with each alternately conducting for each half cycle so that the transistor 62 conducts when the output terminal 13 is positive and transistor 61 conducts when the output terminal 14 is positive. The signal that appears in the transformer winding 59*a* is utilized to decrease the conduction of the transistors by varying the base-emitter potential. Thus the voltage that appears at the junction of the resistances 67 and 70 and hence across the resistance 63 is changed by a circuit that includes the positive ground 43, resistance 63, resistance 67, transistor 61 and lead 64 for one polarity of the half cycle and through the positive ground 43, resistance 63, resistance 70, transistor 62 and lead 68 for the half cycle of the opposite polarity.

It will be appreciated that varying the conduction of the emitter-collector of either transistor 61 or 62 that the voltage across the resistance 63 may be varied. Thus as a signal appears in the winding 59*b* which shows that the output voltage is higher than that desired, the transistors 61 or 62 will conduct less which accordingly makes the potential across the resistance 63 lower. On the other hand, if the output voltage is lower than that desired, the transistors 61 and 62 conduct more which makes the potential across the resistance 63 higher. It will be understood that the bridge 32 is set to balance, i.e. produce a zero signal at a value higher than the output voltage desired and thus produces a signal to the transistors 61 and 62 which is of the same polarity but varies in magnitude.

The signal from the amplifying discriminating circuit appearing as a voltage across the resistor 63 is employed in the firing circuit 31 to control the time in each half cycle when one of the SCR's is rendered conducting. The firing circuit includes a pulse transformer 73 having one secondary winding 74 connected between the gate and cathode of the semiconductor 24 and another secondary winding 75 being connected between the gate and cathode of semiconductor 25. The primary of the transformer is in the base-emitter circuit of a unijunction transistor 76 which includes a capacitor 77 while the other base 78 of the unijunction transistor is connected to a lead 79 that is connected to the positive side of a power supply 80, the negative lead being indicated by the reference numeral 81.

The voltage across the capacitor 77 upon reaching a predetermined level, causes conduction through the emitter-base of the transistor 76 to supply a voltage pulse in the winding of transformer 73 which is sufficient to effect either SCR 24 or 25 into a state of conduction. The time in each half cycle when the pulse occurs is controlled by controlling the rate of charging of the capacitor 77 by a resistance 82, an emitter-collector circuit of a transistor 83 and a resistance, the latter being connected to the positive lead 79. The base of transistor 83 is connected through a biasing resistor 84 to the positive lead 79 and also through a lead 85 to the positive end of the resistor 63. The other side of the resistor 63 is connected to an arm 86 of an adjustable potentiometer 87 that is connected in parallel with a Zener diode 88 through a one-way valve 89. A resistance 88*a* is connected in series with the Zener diode between the supply leads 79 and 81.

With this structure, the Zener diode places across the potentiometer a substantially constant voltage which is a reference voltage that is always higher than the voltage across the resistor 63, the latter being related to the unbalance of the bridge. Moreover, the difference is always such as to maintain the transistor 83 in a state of con-

duction through its emitter-collector circuit. Thus as the voltage across the resistor 63 decreases in positive value, there is a difference between it and the reference and this difference appears at the base of transistor 83 to vary the rate of conduction through its emitter-collector circuit. As this controls the rate of charging of the capacitor 77 it also determines when it will have sufficient voltage thereacross to effect discharge through the emitter-base of unijunction transistor 76 to cause a firing pulse to one or the other of the SCR's. The firing circuit functions in every half cycle of the alternating current and which SCR conducts depends on the polarity of the half cycle, SCR 24 conducting only when the input terminal 11 is positive and SCR 25 conducting only when the input terminal 12 is positive.

For placing the unijunction transistor firing circuit at the same initial condition for each half cycle, namely where the capacitor 77 is substantially discharged, there is provided a transistor 90 connected to have its emitter-collector circuit connected in parallel with the bases of the unijunction transistor 76 to the negative lead 81. Normally the transistor 90 is biased to an off condition but at the beginning of each half cycle its emitter-collector circuit conducts to in effect place a short circuit or very low voltage across the bases, which enables the capacitor 77 to substantially completely discharge.

The transistor 90 operating circuit includes a semiconductor bridge 91 which receives its input power from a winding 92 which may be wound on the bucking winding or may be a separate winding as diagrammatically illustrated in FIG. 2 on the common leg 19. In addition a voltage dropping resistor 93 and RC phase elements 94 and 95 are provided in the connection to the winding 92. A resistor 96 is connected to the positive lead 79 and to the base of transistor 91 while another resistor 97 is connected from the base to a corner 91*a* of the bridge with an opposite corner 91*b* being connected to the negative lead 81. Thus with a substantially zero voltage induced in the bucking winding 92, the voltage at the base of the transistor becomes lower than that of the emitter by reason of the path through resistor 96, bridge 91 and corner 91*b* enabling the transistor 90 to conduct to discharge the capacitor 77. However, as soon as there is a voltage induced in the winding 92, it opposes in the bridge the low resistance path, causing an increase in the voltage at the base of transistor 90 which effects a cessation of conduction through its emitter-collector circuit. While the winding 92 is shown as being inductively associated with the same portion of the core leg 19 as the bucking winding 16 the voltage induced in the winding 92 may cease when an SCR is rendered conducting, and thus permit discharging of the capacitor 77 before the end of the half cycle.

Further elements in the firing circuit include condensers 98 and 99 and an RC filter network having elements 100 and 101. A transformer 102 has its primary connected to the output terminals 13 and 14 as shown and provides the power for operating the firing circuit. Also connected to the emitter of the transistor 83 is a resistor 104 while a diode 105 is connected between the emitter and base of transistor 90.

In the operation of the regulator, the bridge is set so that it is balanced at a higher voltage than that desired at the output voltage and hence continually produces a signal whose magnitude is indicative of the deviation from the balance voltage and also from the actual output voltage. The signal is amplified for one polarity of the alternating current half cycles through the transistors 41 and 54 for the half cycles of the other polarity through the transistors 42 and 55. The signal thus produced appears as an A.C. voltage in the secondary winding of the transformer 59. The transistors 61 and 62 are maintained in a state of conduction and the value of the signal from the sensing bridge changes the conduction of these transistors. The potentiometer arm 86 is set to provide a voltage at the resistor 63 which though positive is higher than the voltage at the positive supply 43 and hence as the conduction of the transistors 61 and 62 decreases, the potential at the base of the transistor 83 with respect to the emitter thereof also decreases by reason of the difference between the reference voltage and the voltage across the resistor 63 decreasing. This slows the rate of charging of the capacitor 77 to cause the signal to the SCR 24 or 25 to occur later in the half cycle. Thus the bucking winding has induced therein a bucking voltage for a longer duration of the half cycle so as to cause the output voltage to decrease. If the value of output voltage is lower than that desired, the transistors 61 and 62 are caused to conduct more, decreasing the value of the potential at the base of transistor 83 which causes an increase in the rate of charging of the condenser 77 with a consequent short circuiting of the bucking winding earlier in the cycle to thereby decrease the effect of the bucking winding induced voltage and hence cause an increase in the output voltage to the desired value.

The embodiment of the automatic voltage regulator heretofore disclosed in connection with FIGS. 1 through 3 inclusive regulated the output voltage by the short-circuiting of the bucking winding and further embodiments of the invention shown in FIGS. 4 through 6 also provide for short-circuiting to effect regulation. These latter embodiments rather than having a separate bypass circuit through which the regulator output current may pass have the output current pass partially or completely through the bucking winding. In all the embodiments though, the bucking winding is short-circuited at an intermediate point in each half cycle of alternating current voltage to cause the flux in the common leg 19 to shift from the path 22 to the path 23 and hence delete the bucking voltage from the output voltage.

In FIG. 4, the regulator is denoted by the reference numeral 120 and includes the input terminals 11 and 12 and output terminals 13 and 14 together with the main winding 17, the adding winding 15 and the bucking winding 16 all mounted on the core 18 in the same manner shown in FIG. 2. In addition there is provided the detector circuit 30 and the firing circuit 31.

In this embodiment, a pair of silicon controlled rectifiers 121 and 122 are connected forwardly between each end of the bucking winding 16 and to a center tap 123 on the bucking winding 16. The gates of the two SCR's as well as the center tap are connected to the firing circuit 31. With this construction it of course will be appreciated that the circuit shown in FIG. 3 may be utilized to control the firing of the SCR's 121 and 122. Upon the detector circuit 30 indicating to the firing circuit 31 that the output voltage is too low and hence the bucking voltage 16 must be substantially decreased for the half cycle of alternating current when the terminal 11 is positive, the SCR 121 at some point during this half cycle is caused to be conductive which short-circuits the half 16*a* of the bucking winding 16. This in turn is reflected by magnetic coupling to the portion 16*b* of the bucking winding causing it in turn to also become short-circuited. Thus the bucking winding 16 becomes short-circuited and the output current may thus flow through either or both the SCR 121 and the portion 16*a* and then the portion 16*b* to provide for regulation of the output voltage.

In the further embodiment of the invention shown in FIG. 5, rather than employ a bucking winding short-circuiting means that utilizes SCR's, this embodiment, generally indicated by the reference numeral 130, substitutes a magnetic amplifier 131 for the SCR's in order to achieve a short-circuiting of the winding portions 16*a* or 16*b*. Thus, in the regulator 130 there is again provided input terminals 11 and 12 and output terminals 13 and 14 together with a main winding 17, an adding winding 15 and a bucking winding 16, all mounted on the core 18 in the manner shown with respect to the regulator 10. The magnetic amplifier 131 includes a first gate winding 132 and another gate winding 133 together with control

windings 134 and 135 mounted on magnetic cores 136, as is well known in the art. The main winding 132 has one end connected to an end of the portion 16*a* of the bucking winding and its other end through a diode 136 to a center tap 137 of the bucking winding 16. Similarly the control winding 133 is connected to an end of the portion 16*b* of the bucking winding 16 and through a diode 138 to the center tap 137. The control windings 134 and 135 are connected in series to a firing circuit 131, the latter being controlled by a detector circuit 30. The firing circuit 31 may obtain its direct control voltage from across the resistor 84 in the circuit shown in FIG. 3 to effect control over the impedance of the magnetic amplifier, as is accomplished when SCR's are controlled in the other embodiments.

In the operation of regulator 130, when the detector circuit determines that the output voltage is too low, it causes a control current to pass through the control windings 134 and 135 which effectively assures the saturation of the reactor 131 causing either the portion 16*a* or the portion 16*b* to become short-circuited, the diodes 136 and 137 determining which portion. This causes shifting of the magnetic flux from the path 22 to the path 23 and an increase in the output voltage. The output current may for the half cycle when the terminal 11 is positive and the portion 16*a* short-circuited, split between the portion 16*a* and the main winding 132 and then pass through the portion 16*b* which again by reason of magnetic coupling also becomes short-circuited.

In the further embodiment of the invention, schematically shown in FIG. 6, the regulator is generally indicated by the reference numeral 140 and includes input terminals 11 and 12, output terminals 13 and 14 together with a main winding 17, adding winding 15 and a bucking winding 16. In addition there is provided a detector circuit 30 and a firing circuit 31 for firing parallel-inversely connected SCR's 141 and 142. The SCR's are connected across a winding 143 that is wound with the winding 16 on the core 18 so as to effectively provide a transformer having in effect a primary winding that is the bucking winding 16 and a secondary winding, the winding 143. With this structure of a regulator it will be appreciated that when the winding 143 becomes short-circuited as by conduction of one of the SCR's 141 or 142, the short-circuiting is reflected by transformer action into the bucking winding 16 to short-circuit the bucking winding 16 which in turn causes the flux in the leg 19 to shift from the path 22 to the path 23. Accordingly, in this embodiment as in the previous embodiments upon the detector circuit causing the firing circuit to render conducting either of the SCR's, the bucking winding 16 becomes short-circuited thereby preventing the algebraic addition of a bucking voltage to the input voltage. In addition, it will be appreciated that in this embodiment the output current of the regulator has no path to traverse but the short-circuited bucking winding 16 but by reason of being short-circuited, it offers minimum impedance to the flow of current therethrough.

It will accordingly be appreciated that there has been disclosed an automatic voltage regulator of the type that employs the addition of a voltage and the subtraction of a voltage from an input voltage to produce a substantially constant desired value of output voltage. Each embodiment of a regulator as hereinbefore disclosed is not only rapidly responsive by reason of effecting correction during each half cycle but also is compact and relatively efficient requiring little power for its operation and exhibits a low internal impedance. This is achieved by the employment of a short-circuiting means for the bucking winding which not only causes cessation of the induced voltage from the bucking winding to reduce the input voltage but also supplies a very low impedance path for the output current. This low impedance path is in one embodiment entirely through the short-circuited bucking winding and in the other embodiments split between the short-circuited bucking winding and another path that is of low impedance when the bucking winding is short-circuited. It will be appreciated that with this structure a simple and efficient core design may accordingly be utilized.

Variations and modifications may be made within the scope of the claims and portions of the improvements may be used without others.

I claim:

1. An automatic voltage regulator comprising input terminals adapted to be connected to a source of alternating current, a pair of output terminals at which a substantially constant value of output voltage appears, a magnetic core defining a first flux path and an alternate flux path, a main coil wound to be inductively associated with both flux paths, a first winding wound to be inductively associated with both flux paths, a second winding wound to be inductively associated with only the first flux path, means connecting the windings in series to the input terminals for causing said main winding to produce magnetic flux in both of said flux paths and to have one of said first and second windings have a voltage inducible therein that adds to the input voltage and the other of said windings having a voltage inducible therein that opposes said input voltage, means operatively connecting said output terminals with said main winding, said first flux path normally having a lesser reluctance than said alternate flux path, and means for effectively short-circuiting the second winding to increase the reluctance of the first flux path inductively associated with the second winding to thereby limit the voltage inducible in said second winding.

2. The invention as defined in claim 1 in which the core includes a leg about which the main coil, first winding and second winding are inductively associated, said first flux path being through the leg and said alternate flux path including only the portion of the leg with which the main and first windings are associated.

3. The invention as defined in claim 1 in which the core is formed to provide a closed peripheral flux path with a central opening, a leg extending through the opening to have its ends communicating with the peripheral path, said main coil, first and second windings being inductively associated with the leg, said leg including a segment extending from the portion of the leg between the first and second windings to adjacent the peripheral path to provide an air gap between the segment and the path, said alternate flux path including said segment and air gap.

4. An automatic voltage regulator comprising input terminals adapted to be connected to a source of alternating current, a pair of output terminals at which a substantially constant value of output voltage appears, a magnetic core defining a first flux path and an alternate flux path, a main coil wound to be inductively associated with both flux paths, a first winding wound to be inductively associated with both flux paths, a second winding wound to be inductively associated with the first flux path, means connecting the windings in series to the input terminals for causing said main winding to produce magnetic flux in both of said flux paths and to have one of said first and second windings have a voltage inducible therein that adds to the input voltage and the other of said windings having a voltage inducible therein that opposes said input voltage, means operatively connecting said output terminals with said main winding, said first flux path normally having a lesser reluctance than said alternate flux path, means for short-circuiting said second winding whereby said second winding opposes any change in the flux in the first flux path associated therewith upon being short-circuited to thereby limit the voltage inducible in said second winding, means for detecting the volue of the output voltage and producing a signal indicative thereof, and means connected to the short-circuiting means for effecting operation thereof during each half cycle at a time determined by the value of the signal from the detecting means.

5. The invention as defined in claim 4 in which the short-circuiting means includes a short-circuiting winding inductively associated with said second winding and controllable impedance means connected across said short-circuiting winding.

6. The invention as defined in claim 4 in which the means for short-circuiting the second winding includes a path connected to be parallel to at least a portion of said second winding and between the input and output terminals and means for causing said path to have a low impedance when the second winding is short-circuited whereby current between the terminals may flow through said path.

7. The invention as defined in claim 6 in which the last-named path includes a pair of parallel oppositely connected semiconductor elements connected across the second winding.

8. The invention as defined in claim 6 in which the last-named path includes a center tap on said second winding and a semiconductor element connected to each end and to said center tap, with the elements being connected to be conductive in the same direction.

9. The invention as defined in claim 6 in which the last-named path includes a center tap on said second winding, a magnetic amplifier having a first load winding connected between said center tap and one end of said second winding and another load winding connected between said center tap and the other end of said second winding.

10. The invention as defined in claim 4 in which the second winding has two portions magnetically coupled to each other and in which the short-circuiting means short-circuits only one of said portions and the other portion becomes short-circuited by the magnetic coupling therebetween.

11. An automatic voltage regulator comprising input terminals adapted to be connected to a source of alternating current, a pair of output terminals at which a substantially constant value of output voltage appears, a closed magnetic core having a leg, a main winding wound to be inductively associated with said leg, an adding winding wound to be inductively associated with said leg, a bucking winding wound to be inductively associated with said leg, means connecting the windings in series to the input terminals for causing said main winding to produce magnetic flux in both of said flux paths and to have said adding winding have a voltage induced therein that adds to the input voltage and said bucking winding having a voltage induced therein that opposes said input voltage, means paralleling said bucking winding to provide an alternate path for the output current, means operatively connecting said output terminals with said main winding, means for controlling the flow of output current between said bucking winding and said alternate path to vary the value of the opposing voltage to thereby maintain the output voltage substantially constant, said means including a pair of semiconductor elements connected in parallel, and means for causing one of said elements to become conductive during each half cycle of alternating current of one polarity and for causing the other element to become conductive during each half cycle of alternating current of the other polarity.

12. The invention as defined in claim 11 in which the last-named means includes means for detecting the value of the output voltage and producing a signal indicative of this value and trigger means operative during each half cycle at a time determined by the signal from the detecting means.

13. The invention as defined in claim 11 in which the semiconductor elements are each silicon controlled rectifiers and the last-named means provides a signal to said rectifiers for causing conduction thereof.

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