Dec. 12, 1967 F. GROSSOEHME 3,358,210

VOLTAGE REGULATOR

Filed June 25, 1964

FIG. 1

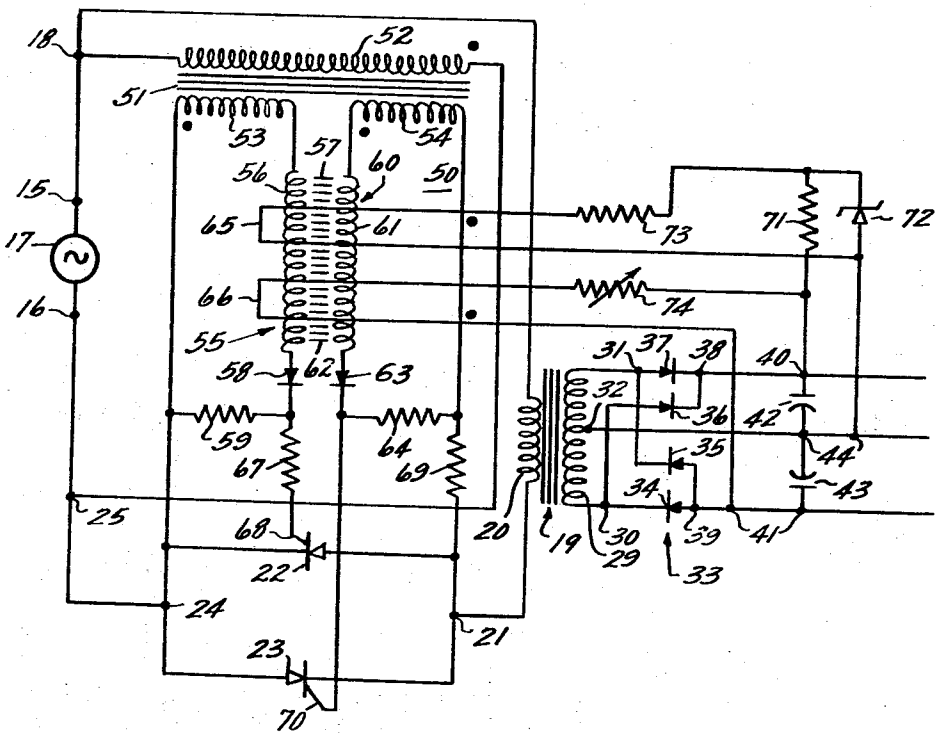


FIG. 2

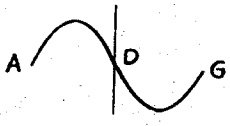


FIG. 3

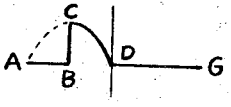


FIG. 4

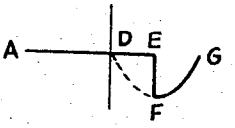


FIG. 5

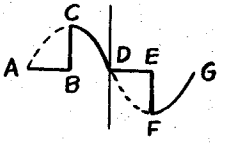


FIG. 6

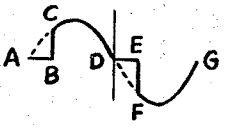
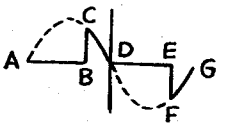


FIG. 7



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VOLTAGE REGULATOR

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This invention relates to a voltage regulator and more particularly to a voltage regulator utilizing electric current valves to control the voltage output.

In certain applications such as control systems and the like it is necessary to provide a regulated direct current voltage as the source of power. However, while a regulated DC source is necessary frequently it need only be regulated to within specified limits to be used to power the control circuit or may otherwise be fed through another voltage regulator to obtain a more closely regulated DC voltage. In such voltage regulation it is important to provide a feedback loop to sense the output of the circuit for voltage regulation within the limits of the regulator. It is additionally important for such a regulating circuit to operate over a wide frequency range in a manner to provide a regulator suitable for universal application.

It is therefore the object of this invention to provide a voltage regulator having a wide frequency range capability and utilizing a feedback system for output voltage regulation.

In a preferred embodiment of the invention there is provided a voltage regulator wherein the input signal is supplied to a distribution transformer primary winding in series connection with parallel and opposed connected current valves, with the primary winding of a control transformer also connected in parallel across the input terminals having secondaries connected through control circuits to saturable reactors in a manner such that each controls the electric current conduction of one of the current valves with the saturable reactors having bias windings providing reference and feedback signals responsive to the output of the distribution transformer in a manner such that conduction through the control circuits is controlled by the feedback signal and in turn controls the electric current conduction through the current valves to regulate the signal supplied to the primary of the distribution transformer and in turn regulate the voltage output from the distribution transformer.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a schematic diagram of one embodiment of the invention,

FIG. 2 represents a wave form of the voltage signal at the input terminals of the regulator,

FIG. 3 represents a wave form of the voltage signal through one branch of the control circuit,

FIG. 4 represents a wave form of the voltage signal through the other branch of the control circuit,

FIGS. 5, 6 and 7 represent voltage signals at the output transformer of the regulator.

Referring now to FIG. 1 illustrating a preferred embodiment of the invention, the regulator circuit is illustrated in schematic form comprising a pair of terminals 15 and 16 to which is applied an unregulated alternating current signal from a source 17. Tracing the power circuit of the regulator from the terminal 15 through the juncture 18 power is supplied to a distribution transformer 19 by electric current flow through the primary winding 20 to the juncture 21 where the current may thereafter pass through one of the electric current valves

or silicon control rectifiers with the choice of which valve depending upon the direction of current flow or the half-cycle of the alternating current source, and thereafter flow through the terminal 24 and terminal 25 to the terminal 16 and the alternating current source 17.

The secondary circuit of transformer 19 includes secondary winding 29 having terminals 30 and 31 with a center tap terminal 32. Connected across the terminals 30 and 31 is a full wave rectifier 33 comprising rectifiers 34, 35, 36 and 37 such that current flows out of terminal 38 and back into terminal 39 of the transformer secondary 29 in a manner to provide direct current flow through the terminals 40 and 41. Filter capacitors 42 and 43 are connected between the center tap of the transformer at terminal 44 and the terminals 40 and 41 to provide a low-reactance path for alternating currents and further smooth out the direct current flow.

However voltage supplied to the secondary in this form will be unregulated, that is it will vary with the voltage level of that supplied from the source 17, for instance if this source is driven by an internal combustion engine such as a turbojet as the engine speed increases the voltage level and frequency will change and the voltage level of the output will change giving an unregulated voltage at the terminals 40 and 41. To overcome this the control circuit 50 is provided which senses the voltage output of the circuit and regulates the output within specified limits. The control circuit comprises a transformer 51 having a primary winding 52 and secondary windings 53 and 54 with the polarities indicated conventionally by the dots. The primary winding 52 is connected across the terminals 18 and 25 which places them in series connection with the alternating current source 17. This control circuit including the primary winding 52 presents a high impedance to control current flow, therefore, most of the current from the alternating current source 17 passes through the primary winding 20 of the distribution circuit of the distribution transformer which supplies the output power current for the regulator thereby making the regulator more efficient. The secondary winding 53 impresses a voltage across the series circuit including the gate winding 56 of the current valve or saturable transformer 55 having an iron core 57, and thereafter through a diode 58 and a load resistor 59 back to the other terminal of the secondary winding 53. Similarly the secondary winding 54 impresses a voltage across the gate winding 61 of the saturable reactor 60 having an iron core 62, the diode 63 and the load resistor 64 back to the secondary winding 54. The gate windings 56 and 61 are positioned on toroidal square loop cores having control windings 65 and 66 such that at some point during each half-cycle the voltage supplied by either the secondary windings 53 or 54 will pass a current through the associated gate winding 56 or 61 creating a flux density which when added to that of the control windings 65 and 66 will cause the reactor to saturate and thereafter represent substantially a short circuit through the diode 58 or 63 to impress a voltage across the load resistor 59 or 64 depending upon the polarity of the primary winding 52. While an iron core saturable reactor is illustrated it should be understood that other types of current valves could be utilized.

Referring now to FIG. 2 which represents one cycle of the alternating voltage as seen across the input terminals of the regulator and across the winding 52 while FIG. 3 represents the current flow through one branch of the control circuit through winding 53, gate winding 56 and load resistor 59 with the curve from the points A to B representing the non-saturated state of the core 57 of the winding 56 during the time which the core 57 has not saturated thereby causing winding 56 to represent a high impedance to current flow. At point B the core 57

saturates and the current rises sharply to point C since the impedance of the coil 56 now represents essentially a short circuit until the alternator voltage returns to zero at point D at which time the diode 58 prevents the current flow in the opposing direction within this circuit. Thereafter for the next half-cycle the circuit of the secondary winding 54 acts in the same manner with the voltage signal as illustrated in FIG. 4.

At point C there is a sudden rise in voltage across the load resistor 59 due to the increased current flow which occurs after core saturation. A current limiting resistor 67 and the gate or control electrode 68 of a current valve or silicon contol rectifier 22 are connected in parallel with this voltage being impressed thereacross with a portion of this voltage causing the rectifier 22 to switch from a non-conducting to the conducting state in the known manner. The rectifier 22 continues in the conductive state until the alternator voltage returns to zero when it again returns to a non-conducting state. During the period of the cycle in FIG. 3 from points C to D the alternating current source 17 is connected through the conducting silicon control rectifier 22 to the primary winding 20 of the distribution transformer 19. During the second half-cycle or from point D to point G of the voltage curve of FIG. 2 the silicon control rectifier 22 is back biased and is thus non-conducting. However, since the diodes 58 and 63 are connected in an opposing voltage relationship during this half-cycle from points D to G on the curve the control circuit including the secondary winding 54 controls and operates in the same manner as that circuit of winding 53 to supply a voltage across the load resistor 64. Thus since the current limiting resistor 69 and gate or control electrode 70 are connected in parallel with this resistor, a portion of this voltage is supplied to the control electrode 70 of the silicon control rectifier 23 which operates in the manner as rectifier 22 or as illustrated in the current flow curve of FIG. 4 such that upon saturation of the saturable reactor core 62, which occurs at point E, the current immediately jumps to that illustrated at point F since the reactor winding 61 is now substantially a short circuit, and follows the voltage curve to G at which time the voltage again reaches zero and the diode 63 prevents a reversal in current flow.

Thus it can be seen that current flow during each half-cycle is controlled by either the control circuit including the secondary winding 53 or by the circuit including secondary winding 54 with the conduction of the current valves or silicon control rectifiers 22 and 23 controlled regulated by the saturation point at which the saturable cores 57 and 62 saturate. Thus the current flow for each half-cycle is controlled through the primary winding 20 of the distribution transformer 19 regardless of the direction of current flow with the total flow generally as illustrated in FIGS. 5 through 7. As illustrated in these figures the amount of current flow per half-cycle may be controlled by regulating the saturation point of the saturable reactors 55 and 60 which in turn controls the firing or conduction of the electric current valves 22 and 23. These valves 22 and 23 control current flow through the primary of the distribution transformer 19. If the silicon control rectifiers 22 and 23 are caused to fire earlier during each half-cycle the current flow through the winding 20 is as illustrated in FIG. 6 and if the control rectifiers are caused to fire later in each half-cycle the voltage or current curve is as illustrated in FIG. 7.

To control the saturation of the saturable reactors 55 and 60 and thereby control the current flow through the distribution primary winding 20 as heretofore described control windings 65 and 66 on the saturable reactors 56 and 60 respectively are provided which are connected to control the saturation of these saturable reactors responsive to the output voltage of the distribution transformer as detected at the junctions 40 and 41. By the manner in which the voltage from the secondary winding 30 of the distribution transformer is conducted through the full wave rectifier 33, the juncture 40 is always positive with respect to the juncture 44 and the juncture 41 is always at a negative potential with respect to the juncture 44. The voltage between juncture 40 and juncture 44 is supplied across the series combination of a resistor 71 and a Zener diode 72. The Zener diode 72 has a breakdown voltage lower than the voltage across the junctures 40 to 44 while the resistor 71 limits the current through the diode to that desired value. By the regulating action of the Zener diode 72 in the normal manner the voltage across the Zener diode 72 is maintained a constant value and this voltage is applied across the control winding 65 through a current control resistor 73 to establish a control current for the saturable reactors of the control circuit 50. Since the voltage across the Zener diode 72 is constant the control current through the control winding 65 will remain constant and therefore serve as a constant reference current establishing a constant reference flux in the cores 57 and 62. Current is also caused to flow through the control winding 66 from the juncture 40 through the current limiting resistor 74 and this control winding back to the juncture 41 with this current responsive to the voltage potential across the juncture 40 to 41 or that voltage representing the output of the distribution transformer 19. The voltage which the subject regulator will maintain across the junctures 40 to 41 is made adjustable by adjustment of the value of the variable resistor 74. The primary to secondary turns ratio of the transformer 19 is set so that the voltage of alternating current source 17 is slightly larger than that required to produce the desired voltages across the junctures 40 to 41 at the lowest alternator frequency where operation is desired.

Since, as indicated by the polarities of the control windings 65 and 66 these windings present an opposing or bucking flux in the saturable reactor cores 57 and 62 the firing angles or points of the silicon control rectifiers 22 and 23 are controlled by the relationship or additive effect of the currents through these control windings by controlling the saturation levels of the saturable reactors. For instance if the voltage across the junctions 40 and 41 increases causing a corresponding increase in the voltage across the control winding 66, the flux level of the saturable reactor in the direction opposing the constant reference flux resulting from winding 65 is decreased so as to slow the saturation of the reactors and thereby slow the firing of the control rectifiers such that the voltage across the junctures 40 and 41 is again decreased to the desired regulated level. This delay in the firing of control rectifiers 22 and 23 will cause a current flow through the primary winding 20 of the distribution transformer 19 to approach that illustrated in FIG. 7 which serves to decrease the current or voltage output of the distribution transformer secondary winding 30 to that point at which the current through the control winding 66 responsive to the voltage across the junctures 40 and 41 is at the level which the regulator is set to sustain. Similarly a decrease in voltage across the junctures 40 and 41 will serve to decrease the voltage and resulting flux of the winding 66 allowing the current through winding 65 to increase the flux level in the cores in a direction to cause an earlier firing of the silicon control rectifiers 22 and 23 during each cycle as illustrated in FIG. 6 to restore the current through the secondary winding 30 of the distribution transformer 19 to the level necessary to induce the desired voltage and current in the secondary circuit as detected across the junctions 40 and 41.

In this manner the subject regulator serves to control the voltage output irrespective of frequency input since the total circuit operates from the same power source signal. While particular embodiments of the invention have been illustrated and described, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the invention and it is intended to cover in the appended claims all

such changes and modifications that come within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a rectifier having an alternating current input and a direct current output,

means for regulating the potential of the direct current output comprising,

silicon-controlled rectifier means connected in series with the alternating current input,

magnetic amplifier means having two control windings,

a fixed reference voltage connected across one control winding, thereby providing a constant reference current therethrough, the other winding being connected across the direct current output providing a variable current flow fluctuating as the direct output potential fluctuates, and

means connecting the output of said magnetic amplifier to said silicon-controlled rectifier means and controlling the firing thereof to vary the alternating current input to the rectifier inversely to changes in the direct current output potential.

2. In a rectifier as in claim 1 wherein,

the silicon-controlled rectifier means comprise a pair of oppositely poled silicon-controlled rectifiers, each having a control electrode and

the magnetic amplifier means comprise a pair of gate windings of opposite polarity, driven from said alternating input with the gate windings being respectively connected to the control electrodes of the silicon-controlled rectifiers.

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