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[54] **LOW DISTORTION AUTOMATIC VOLTAGE REGULATOR HAVING CONTROLLED RECTIFIERS**
6 Claims, 1 Drawing Fig.

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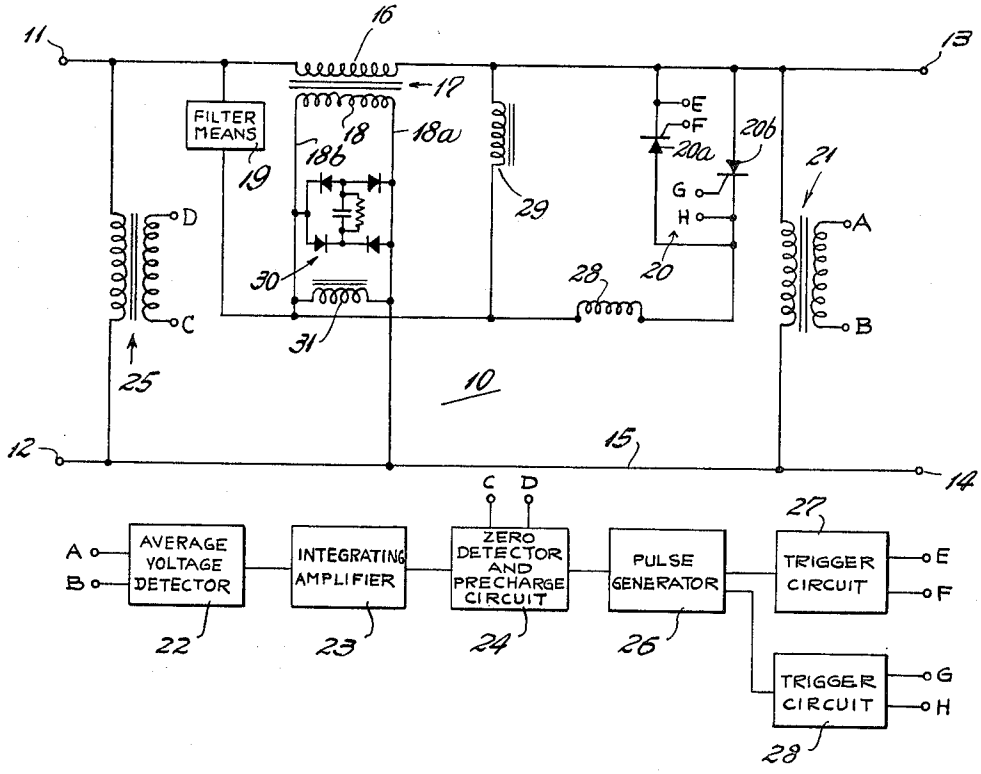
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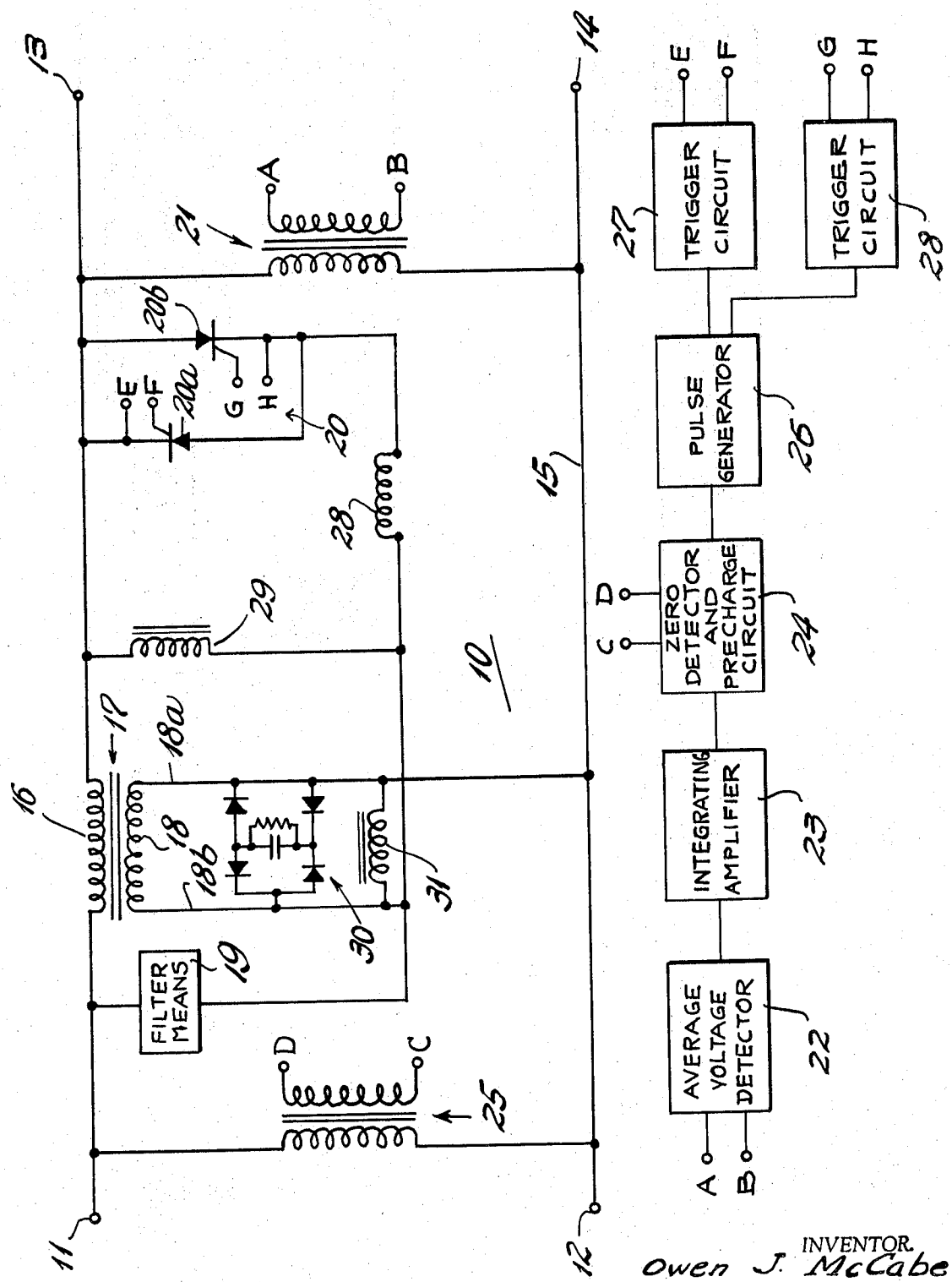
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ABSTRACT: An automatic voltage regulator for providing a substantially constant output voltage by regulating the input voltage with a transformer that has a secondary winding connected between the input and output of the regulator and a primary winding connected to controlled rectifiers so that control of the conduction of the rectifiers alters the voltage in the transformer to regulate the input voltage. A harmonic voltage filter is also connected to the primary winding in parallel with the controlled rectifiers to substantially minimize the percentage of distortion caused by the controlled rectifiers in the output of the regulator by shunting the harmonic voltages back to the controlled rectifiers. The filter also provides a voltage that is in opposition to the controlled rectifier voltage in the primary winding and is employed to regulate the input voltage at some operating conditions of the regulator.





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LOW DISTORTION AUTOMATIC VOLTAGE REGULATOR HAVING CONTROLLED RECTIFIERS

In the regulating of AC voltage, when the input voltage is altered to maintain a desired value of output voltage, it is extremely desirable to have the output voltage be altered only in value from the input voltage. A change in the wave form, however, generally occurs, it is called distortion and is usually measured as a percentage of the output voltage. The percentage is usually quite large in regulators which employ switching type devices, such as controlled rectifiers in their regulating circuit and thus in many instances, the use of controlled rectifiers has not been found satisfactory because of the unacceptable high value of distortion which they create. It is however advantageous to utilize semiconductor switching means because of their low cost, high power handling capabilities and relative simplicity of control.

It is accordingly an object of the present invention to provide an automatic voltage regulator which has a level of distortion in its output voltage which is relatively low but yet still employs semiconductors in its regulating circuit.

Another object of the present invention is to provide an automatic voltage regulator which provides for maintaining a constant value of output voltage over a large range of values of input voltage.

A further object of the present invention is to provide an automatic voltage regulator which while achieving the above objects is relatively economical and simple in design.

In carrying out the present invention, the herein disclosed regulator has a pair of input terminals connectable to a source of AC and a pair of output terminals at which the desired value of output voltage is maintained constant. One input terminal is connected to one output terminal with a secondary winding of a buck-boost transformer connected inbetween to be in series therewith. The primary winding of the transformer has an adjustable value of voltage applied thereacross which is either added or subtracted from the input voltage to provide the constant value of output voltage.

The primary winding of the transformer has one end effectively connected to the common of the regulator (a common connection between input and output terminals) while its other end is connected in parallel to a distortion filter means and to a controlled rectifier means. The filter means is also connected to one input terminal while the controlled rectifier means is connected to the output terminal so that the secondary winding of the transformer is located between the two connections. The controlled rectifier means has its periods of conduction varied in order to provide in the primary and hence in the secondary winding a voltage which is additive to the value of the input voltage to maintain the desired value of output voltage.

The operation of the controlled rectifier means creates voltages having frequencies which are odd numbered multiples of the fundamental frequency of the AC input voltage with the third harmonic being predominant, then the fifth, seventh, etc. being of generally decreasing magnitude. The filter means is designed to provide a low impedance shunt path for the harmonic frequency voltages and a higher impedance path for the fundamental frequency voltage. The connection of the filter means serves to minimize the appearance of the harmonic frequency voltages at the output terminals to thereby decrease the distortion at the output terminals by providing a relatively low impedance path for them through the filter means and the secondary winding back to the controlled rectifier means. As the filter means may have series tuned circuits for preferably the third, fifth and seventh harmonics, it accordingly permits a large percentage of the harmonic frequency voltages to be maintained away from the output terminals.

In addition to providing a shunt path for the harmonic frequency voltages, the filter means also permits a limited quantity of fundamental frequency current to pass therethrough from one input terminal to the other. This current decreases the value of the effective input voltage at the transformer and requires that during most operating conditions even when the input voltage is higher than the output voltage that the voltage added by the transformer be a boosting voltage whose value is selected by the regulation of conduction of the controlled rectifier means. Moreover, the filter means current develops a voltage in the transformer which is in opposition to the boosting controlled rectifier voltage and at conditions of very low conduction of the controlled rectifier means, the filter voltage is the greater and provides a bucking voltage in the transformer, thus increasing the range over which the regulator is operable.

Other features and advantages will hereinafter appear.

The sole FIGURE is a block and schematic diagram of the automatic voltage regulator of the present invention.

Referring to the drawing, the regulator is generally indicated by the reference numeral 10 and includes a pair of input terminals 11 and 12 and a pair of output terminals 13 and 14. A source of alternating current having a fundamental frequency is connectable to the input terminals 11 and 12 and though its voltage value may vary, a constant value of output voltage appears across the output terminals 13 and 14. A common 15 connects the terminals 12 and 14 while a secondary winding 16 of a transformer 17 is connected between the terminals 11 and 13.

The transformer 17 further includes a primary winding 18 and in accordance with the present invention, a variable value of voltage is impressed across the primary winding to appear in the secondary winding 16. This regulating the primary voltage is algebraically added to the input voltage to thus maintain the output voltage constant with changes in the value of the input voltage.

One end 18*a* of the winding 18 is connected to the common 15 while its other end 18*b* is connected through filter means 19 to the end of the secondary winding that is connected to the input terminal 11. In addition, controlled rectifier means 20 consisting, specifically as shown, of a pair of inversely parallel connected silicon controlled rectifiers 20*a* and 20*b* is connected to the end 18*b* and also to the other end of the winding 16 that is connected to the output terminal 13.

The controlled rectifier means 20 permits, when conducting, a current to flow through the winding 18 to the common 15 which produces a voltage in the winding 18 and hence a voltage in the winding 16. The value of the voltage in the winding 16 is altered by controlling the time in each half cycle of AC when the controlled rectifier means is caused to be conducting. The earlier the occurrence of time, the more conduction occurs and the larger the voltage in the winding 16.

For phase controlling the conduction time of the controlled rectifier means, there is provided a transformer 21 connected across the output terminals 13 and 14 and having secondary winding terminals A and B which are connected to be the input to an average voltage detector 22. The average voltage detector may be a Zener diode bridge or other sensing circuit and furnishes a signal related to the value of the output voltage to an integrating amplifier 23 which modifies the signal and provides a control voltage to a zero detector and precharge circuit 24. Additionally the circuit 24 has terminals C and D which are connected to terminals C and D of a transformer 25 connected across the input terminals 11 and 12 with the transformer 25 providing to the circuit 24 a voltage that is phase related to the input voltage. The circuit 24 determines the time in each half cycle when the controlled rectifier means 20 should be rendered conducting by producing a signal to a pulse generator 26 which is essentially a unijunction oscillator. The pulse generator has one output which controls a trigger circuit 27 and another output which controls an identical trigger circuit 28. The trigger circuit 27 has terminals E and F connected to the gate and cathode of the controlled rectifier 20*a* while the trigger circuit 28 has terminals G and H connected to the gate and cathode of the controlled rectifier 28*b*.

Basically, each trigger circuit functions as a slave or pilot controlled rectifier so that it utilizes a small sensitive control rectifier which when actuated maintains its conduction for the duration of each half cycle in which it is made to be conducting. The controlled rectifiers 20*a* and 20*b* follow the conduc-

tion of the trigger circuits. It will be understood that the trigger circuits may be eliminated and the pulse generator signal applied directly to the rectifiers 20*a* and 20*b*. However, the trigger circuits by utilizing smaller, more precise and sensitive controlled rectifiers than the rectifiers 10*a* and 20*b* enable more accurate control, a smaller control signal, and in addition enable the trigger circuits to be usable with any of the various sizes of rectifiers 20*a* and 20*b*. For a more detailed description of the components of the regulating portion of the transformer which controls the time of conduction in each half cycle of the controlled rectifiers, reference is made to U.S. Pat. No. 3,408,558.

The use of controlled rectifiers in a voltage regulator has heretofore presented difficulties in maintaining the percentage of distortion that appears across the output terminals of the regulator within an acceptable minimum, one minimum may be 3 percent. The rectifiers when rendered conducting produce voltages which have frequencies that are harmonics of the fundamental frequency of the input AC voltage with the third harmonic frequency voltage being predominant, then the fifth, seventh, etc. Normally the quantity of these harmonic frequency voltages are such that if they appeared in the output voltage they would render the percentage of distortion beyond acceptable limits. The filter means 19 provides a low impedance path for harmonic frequency currents. For each frequency to be filtered, there is provided a series tuned circuit of a capacitor and an inductor connected in series and tuned to one of the harmonic frequencies. Preferably, there are three circuits with the circuits being connected in parallel and tuned to harmonic frequencies of the third, fifth and seventh harmonics of the input voltage frequency which in the case of a 400 c.p.s. AC input voltage would be frequencies of 1,200 c.p.s., 2,000 c.p.s. and 2,800 c.p.s. Thus when harmonic frequency voltages are generated by the controlled rectifier means they will pass readily through the filter 19 and through the secondary winding 16 back to the controlled rectifier means which generates them. Accordingly they are maintained substantially free from the output terminals.

The filters 19 normally are capable of passing perhaps 80 percent of the harmonic frequency voltages at which they are tuned, thus leaving only about 20 percent to pass through the winding 18 and to the common 15. The harmonic frequency voltages at the common 15 will have two paths back to the controlled rectifier means, with one path being through the AC source generator connected to the input terminals and the other path being across a load connectable across the output terminals. The division of the harmonic frequency voltages will depend upon the relative impedances across the input terminals and the output terminals and with a low impedance source and a high impedance load, the percentage of the distortion across the output terminals is thus even further minimized.

While the harmonic frequency currents passing through the transformer winding 16 will induce voltages related thereto in the winding 18, the components in the path of these currents, such as the filter means, tend to make the induced voltages out of phase with the harmonic frequency voltages being induces in the winding 18 by the portion of the harmonic frequency current that flows therethrough so that there is some cancellation of each.

It has been found that the filters 19 while tuned to the different harmonic frequency voltages, will also pass a small quantity of current of the fundamental or source frequency through the winding 18 to the common 15. The current flow decreases the effective value of the input voltage at the transformer winding 16. Thus if the output voltage is desired to be for example 115 volts, and the input voltage on the order of 120 to 125 volts, the effective input voltage at the transformer winding 16 will be less than the desired output voltage of 115 volts which will require a boosting voltage from the controlled rectifier. Thus over most of the range of the input voltage values the controlled rectifier means will conduct. Most conduction of the controlled rectifier means occurs when the value of the input voltage is at its lowest and the value of the output voltage is at its highest with maximum load current passing through the regulator. The least conduction occurs when the value of input voltage has its highest value, the value of output voltage is relatively low and there is substantially little load current. For the latter condition, it has been found that the voltage developed by the current through the filter means in the winding 18 may be greater than the voltage produced by the current through the controlled rectifiers with the algebraic sum of these voltages being reflected in the winding 16. When the filter means developed voltage is the greater, there will be produced in the winding 16 a voltage which is in opposition to the input voltage and will thus permit the regulator to operate at higher values of input voltage than if just the controlled rectifier means produced a boosting voltage. Moreover, as the controlled rectifier means tend to be less sensitive when it conducts very little, the use of the filter means current to produce a bucking voltage enables the regulator to maintain its preciseness at the lower conduction condition of the controlled rectifier means.

It has also been found desirable to provide an impedance choke 28 in series with the winding 18 and the controlled rectifier means to limit the rate of rise of the voltage when the controlled rectifiers are rendered conducting. Additionally the controlled rectifiers may be protected from overvoltages including transients by a peak average voltage saturating choke 29 connected as shown. A further peak voltage suppressing means may be connected across the ends 18*a* and 18*b* of the winding 18 and include a diode resistor capacitor network 30 and a saturating coil 31. One embodiment of the invention has a transformer ratio of 4 to 1 from winding 18 to winding 16 so that transients in the winding 16 would be multiplied in the winding 18 but the coil 31 is designed to saturate well below any voltages which could be harmful to the controlled rectifier means. In the network 30, the diodes shunt the peak voltages for absorption by the capacitor.

It will accordingly be appreciated that there has been disclosed an automatic voltage regulator which is capable of maintaining a desired value of output voltage with an input voltage varying over a relatively wide range of perhaps ± 20 percent of the nominal value of input voltage. Though the regulator employs controlled rectifier means for achieving regulation, the distortion produced thereby is substantially minimal at the output terminals by providing a return path to the controlled rectifiers of the distortion that is of low impedance to the distortion. Thus a substantial portion of the voltages which are generated by the controlled rectifier means and which would normally constitute distortion if present in the output voltage are basically maintained independent of the output terminals.

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

I claim:

1. An automatic voltage regulator comprising a pair of input terminals adapted to be connected to a source of AC output terminals at which a substantially constant value of AC voltage is maintained, a common joining an input and an output terminal, a transformer having a first winding and a second winding, said first winding having one end connected to another input terminal and another end connected to another output terminal, distortion filter means connected between said one end and a first end of the second winding, controlled rectifier means connected between said another end and the first end of the second winding, means connecting the other end of the second winding to the common and means connected to control the conduction of the controlled rectifier means to provide a voltage in the second winding which alters the value of the input voltage to the maintained value of output voltage.

2. The invention as defined in claim 1 in which the controlled rectifier means generates distortion that includes frequencies that are odd number multiples of the frequency of

the AC source and the distortion filter means includes means providing a low impedance path for electric power of at least one of the odd number multiple frequencies.

3. The invention as defined in claim 2 in which the filter means has a relatively high impedance which limits the current flow of the fundamental frequency, said current flowing through said second winding in a direction opposite to current flow controlled by the controlled rectifier means.

4. The invention as defined in claim 3 in which the current flow controlled by the controlled rectifiers produces a voltage in the first winding which is additive to the input voltage and in which the current flow through the filter means produces a voltage in the first winding which is subtractive from the input voltage.

5. The invention as defined in claim 4 in which the current flow through the filter means has a value greater than the current flow controlled by the controlled rectifier means for the minimum conduction of the controlled rectifiers.

6. An automatic voltage regulator comprising a pair of input terminals adapted to be connected to an AC source, output terminals at which a substantially constant value of AC voltage is maintained, a common joining an input and an output terminal, a transformer having a first winding and a second winding, said first winding having one end connected to another input terminal and another end connected to another output terminal, controlled rectifier means connected between said another end and the first end of the second winding and capable of producing harmonic distortion upon being rendered conducting, means connecting the other end of the second winding to the common, means connected to control the conduction of the controlled rectifier means to provide a voltage in the second winding which alters the value of the input voltage to the maintained value of the output voltage and means for providing a shunt path of relatively low impedance for the harmonic distortion produced by the controlled rectifier means.