March 30, 1965 L. J. JOHNSON 3,176,214

VOLTAGE STABILIZER

Filed Oct. 24, 1960 2 Sheets-Sheet 1

FIG. 1.

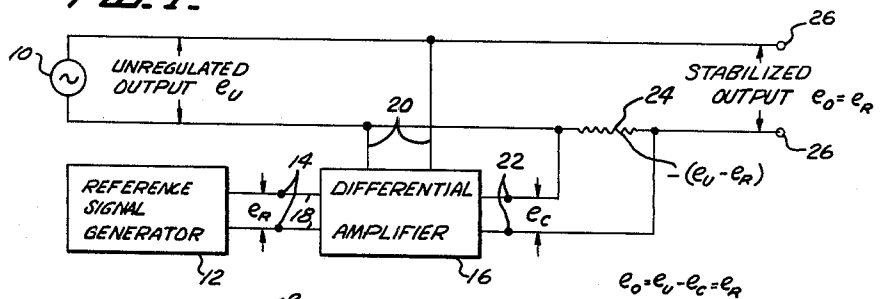


FIG. 2.

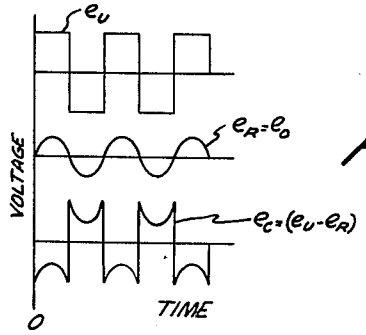
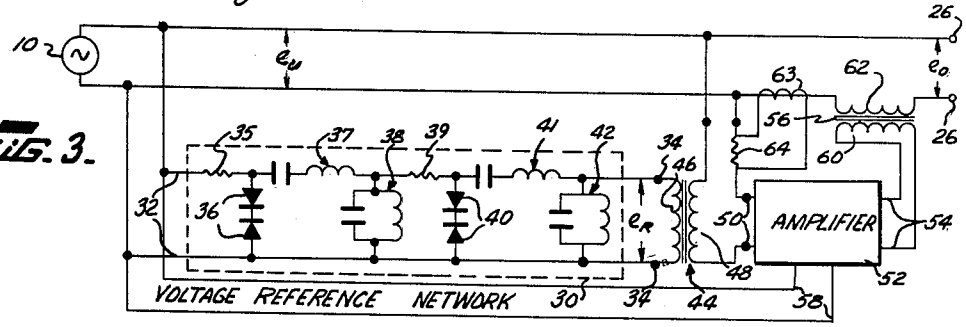


FIG. 3.



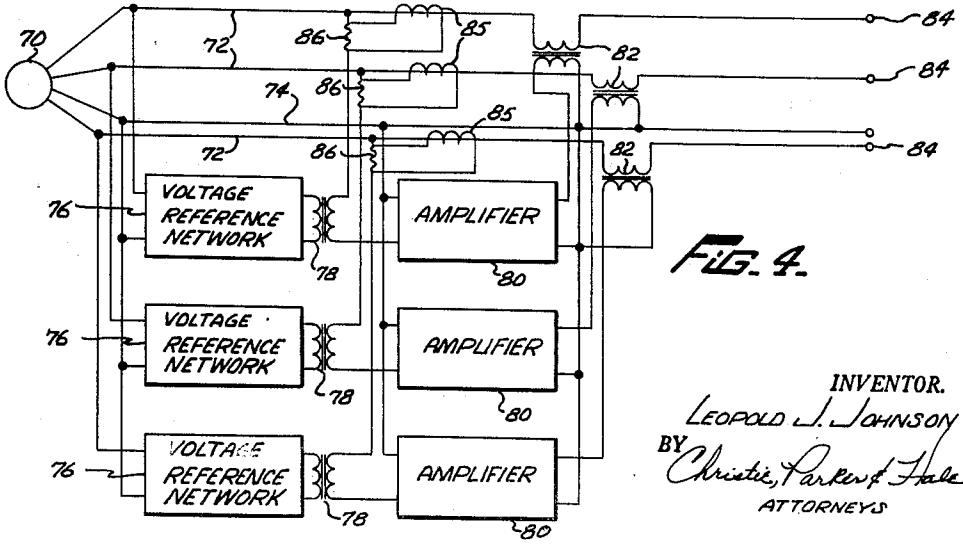


FIG. 4.

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VOLTAGE STABILIZER

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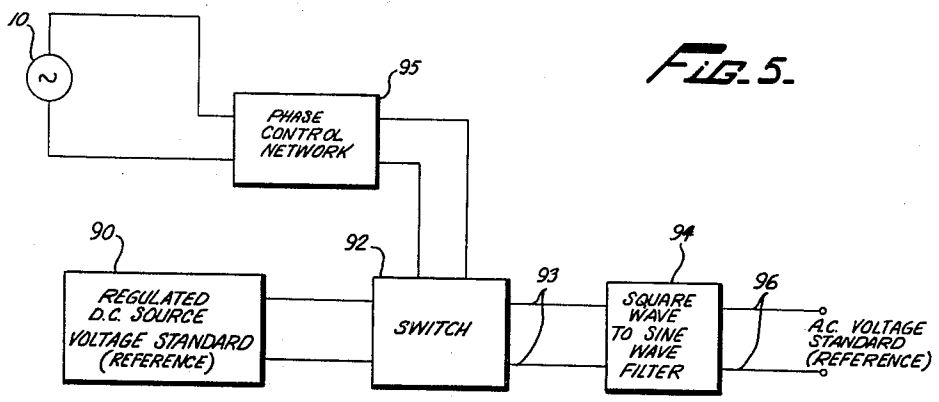


FIG. 5.

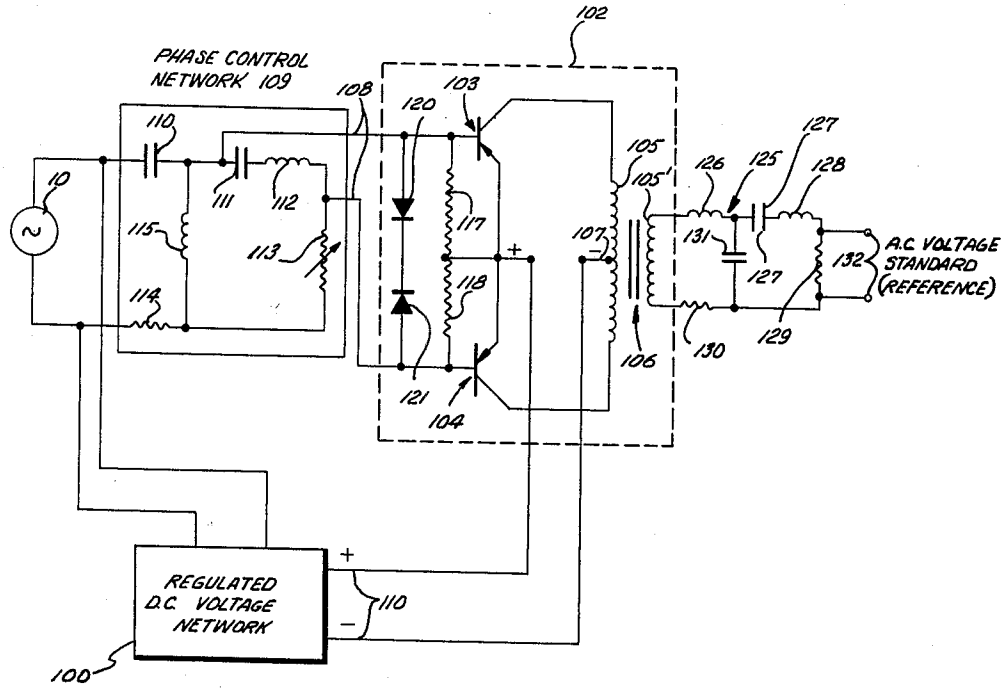


FIG. 6.

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VOLTAGE STABILIZER

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The present invention relates to voltage stabilizers.

Heretofore voltage control has generally been achieved through the use of feedback regulation. Prior art feedback control systems are used extensively where precise voltage control is required. Such systems function by detecting an error signal in the regulated output circuit and utilizing the error signal in a closed loop feedback circuit to reduce the error signal. This type of voltage control system has the disadvantage of requiring an error in the output voltage for the purpose of operating the feedback control circuit.

Such feedback voltage control systems also have poor transient response which renders their use unsatisfactory in many applications. The lack of sufficient transient suppression in prior art voltage control systems has presented serious problems. For example, transient voltage spikes and similar phenomenon have caused serious errors in electronic computers. Feedback control voltage regulators have the additional disadvantage of providing insufficient control of undesired harmonics in the output voltage for many applications. The effect of undesired harmonics generated by some modern day regulators have made it mandatory for the user to employ extra equipment such as radio noise filters and harmonic suppressors. These undesirable transients are due to the inherent delays in the feedback correction circuit. Such delays prevent instantaneous correction of harmonic distortion within the feedback control circuit. To eliminate such harmonics it has been the practice in the past to place passive filter networks in the output or load circuit. Such filter networks are large in size and expensive where the anticipated load current is high.

The above disadvantages are overcome by the present invention which provides voltage stabilization without the necessity of undesirable steady state and transient errors. The voltage stabilizing means of this invention is of a direct compensation type as contrasted with a closed loop feedback type. The voltage stabilizing means provides complete compensation for transient and harmonic distortion. This is possible because the action of the stabilizing means of this invention is not dependent upon any error in the output voltage. In the apparatus of this invention, the output voltage is never sensed for the purpose of controlling its magnitude.

In accordance with this invention a reference signal generating means is provided for generating a reference signal having predetermined electrical characteristics such as waveform, voltage, amplitude and phase. Means are coupled between an unregulated voltage source and the reference signal generating means for obtaining a control signal which is proportional to the instantaneous difference between the unregulated voltage from the source and the reference signal. Means are also provided for coupling a signal representative of the control signal in series with the unregulated source across a pair of output terminals to provide an output voltage which is proportional to the reference signal in waveform and amplitude. Thus the waveform and amplitude of the output voltage are controlled without feedback networks or filters in the output circuit.

The invention is described in more detail by reference to the accompanying drawings in which:

FIG. 1 is a block diagram of a voltage stabilization circuit embodying the principles of the present invention;

FIG. 2 is a graph illustrating one example of the possible waveform of the signals present in the circuit of FIG. 1;

FIG. 3 is a schematic circuit diagram of another embodiment of the present invention;

FIG. 4 is a block diagram of a further embodiment of the present invention;

FIG. 5 is a block diagram of another type of voltage reference network that may be employed in the apparatus of this invention; and

FIG. 6 is a schematic circuit diagram of a particular type of voltage reference network.

Referring now to the drawings and more particularly to FIG. 1, there is shown a source 10 of unregulated output voltage e_u. A reference signal generator 12 having an output circuit 14 is provided for generating a reference signal e_r having predetermined electrical characteristics such as amplitude, waveform and phase as will be more fully described.

A differential amplifier 16 having a pair of input circuits 18 and 20 and an output circuit 22 is provided for obtaining a control signal e_c which is proportional to the instantaneous difference between the unregulated source voltage e_u and the reference signal e_r. The input circuits 18 and 20 of the amplifier 16 are connected across the output circuit of the reference signal generator 12 and the unregulated source 10, respectively as shown. The output circuit 22 of the amplifier 16 is connected across a line impedance such as a resistor 24 to produce a voltage across the resistor 24 which is representative of e_c or $-(e_u-e_r)$. The resistor 24 is connected in series with the unregulated source 10 across a pair of output terminals 26 so that the output voltage e_o established across the terminals 26 is proportional to the reference signal e_r. For example, summing the voltages in the circuit connected to the output terminals 26 provides the following equations:

$$e_o=e_u-(e_u-e_r)$$

or

$$e_o=e_r$$

If desired the differential amplifier 16 may be arranged to provide an output signal e_c which is proportional to the difference between the unregulated voltage e_u and a preselected value of the reference signal such as Ke_r, where K is a constant. The regulated output signal e_o would then be equal to Ke_r.

Referring now to the graph of FIG. 2, the ordinate is representative of voltage and the abscissa is representative of time. In this graph the unregulated voltage e_u is shown as a square wave for illustrative purposes. The reference signal e_r is illustrated as a sine wave which is the desired waveform of the output voltage e_o. The control signal e_c is the difference between the signals e_u and e_r. When the control signal e_c is subtracted from the unregulated output signal e_u by means of the resistor 24 the resulting output signal e_o is identical or proportional to the reference signal e_r in waveform, amplitude and frequency.

The reference signal generator 12 may be a crystal oscillator having low power output signal. The differential amplifier 16 may be of any well known type and may derive its power from any desired source such as the source 10. It should be noted that the unregulated source 10 and the reference signal generator 12 may provide direct or alternating current signals.

Referring now to FIG. 3 there is illustrated a modification of the voltage stabilization circuit of FIG. 1 in which a voltage reference network 30 has an input circuit 32 connected across the unregulated source 10 and an output circuit 34 across which a sine wave reference signal is produced. A resistor 35 and a pair of Zener diodes 36 are connected across the input circuit 32 to clamp the

voltage of the input signal to the network at a predetermined level, for example within a few percent of the peak value of the reference signal. The diodes 36 are illustrated by conventional symbols with the cathodes thereof connected together as shown. A pair of filter networks 37 and 38 including series and parallel coupled capacitors and inductors, respectively, are connected across the Zener diodes 36 for filtering out undesired frequencies from the input signal to establish an approximate sine wave of the desired frequency. A resistor 39 and a second pair of Zener diodes 40 are connected across filter 38 for reducing the amplitude of the input signal to the final predetermined value of the reference signal e_r. Another pair of filter networks 41 and 42 are connected across the Zener diodes 40 for reducing the undesired frequencies of the final sine wave output to within the permissible distortion level, for example .01%. The values and arrangement of the filter components are preferably selected to maintain phase coherence between e_r and e_u.

To obtain the difference between the unregulated voltage e_u and the reference signal e_r subtracting means such as a transformer 44 is provided with a primary winding 46 connected across the output circuit 34 of the voltage reference network 30. The transformer 44 includes a secondary winding 48 which is connected in series between the unregulated source 10, a load current compensating device such as a resistor 64 and an input circuit 50 of an amplifier 52. The primary winding 46 forms a first input circuit of the subtracting means 44 and the secondary winding 48 forms a second input circuit which is connected across the source 10 and an output circuit which is connected to the amplifier 52. The difference or control signal obtained by the transformer 44 may be represented by $(K_1e_u - K_2e_r)$ where K_1 and K_2 are constants.

The amplifier 52 has an output circuit 54 which is coupled through a line transformer 56 between the source 10 and the output terminals 26 as shown. The amplifier 52 also includes a pair of power input terminals 58 which are connected across the source 10 so that the amplifier may take its power from the unregulated source 10. The difference signal which is applied to the input of the amplifier 52 is amplified and applied to primary winding 60 of the transformer 56. The secondary winding 62 of the transformer 56 establishes a voltage which subtracts from or bucks out the undesired components of the voltage from the unregulated source 10 to produce a regulated output signal across the terminals 26 which is proportional to the output signal from the voltage network 30. The current transformer 63 is connected across a resistor 64 which is connected in series with the input circuit 50 of the amplifier 52 to provide additional fine compensation for voltage errors due to load current passage through the transformer 56.

Referring now to FIG. 4 there is illustrated a voltage regulation circuit for a three-phase network in which a source 70 such as an alternator is connected across a three-phase transmission line 72 having a neutral line 74. Three voltage reference networks 76 which may be similar to the network 30 are provided with input circuits which are connected between respective phases of the three-phase line 72 and the neutral line 74. Algebraic subtracting means such as transformers 78 are connected between the output circuits of the respective voltage reference networks 76 and the respective phases of the unregulated line 72 to the input circuits of amplifiers 80 as shown. The amplifiers 80 are connected to respective isolating line transformers 82 for applying desired control signals in the respective phases so that the three-phase output voltage established across output terminals 84 is regulated in accordance with the output signals from the voltage reference networks 76. Current transformers 85 and resistors 86 (similar to the transformer 63 and resistor 64 arrangement of FIG. 3) are provided to compensate for voltage errors resulting from load current flow through the transformers 82.

In FIG. 5 there is illustrated another type of voltage reference network that may be employed to provide a reference voltage for the compensation circuits of FIGS. 1, 3 and 4.

In FIG. 5 a regulated direct current (D.C.) voltage source or reference standard 90 is provided for producing a D.C. output voltage of constant or controlled amplitude. The output from the regulated source 90 is coupled through a switch 92 to a square wave-to-sine wave filter network 94. The switch 92 is controlled from the unregulated source 10 through a phase control network 95. The switch 90 may be of many well known types and serves to provide an output signal across an output circuit 93 thereof which is in the form of a square wave having an amplitude proportional to the amplitude of the reference signal from the D.C. source 90 and having a frequency equal to the frequency of the voltage from the alternating current source 10. The phase control network 95 controls the phase between the square wave output of the switch 92 and the unregulated A.C. source 10. The square wave-to-sine wave filter 94 may be of conventional design and serves to convert the square wave output from the switch 92 to a sine wave signal in the output circuit 96 thereof. The amplitude of the sine wave signal is proportional to the amplitude of the square wave signal in the output circuit 93 of the switch 92. The A.C. voltage reference signal produced across the output circuit 96 of the filter 94 may be applied across the terminals 34 of the transformer 44 in the apparatus of FIG. 3, or may be applied to the input network of FIG. 1. The voltage reference network of FIG. 5 may also be utilized as the reference network 76 in the apparatus of FIG. 4.

Referring now to FIG. 6 there is illustrated a schematic circuit diagram of a particular type of voltage reference network shown in block form in FIG. 5. In FIG. 6, a regulated direct current voltage network 100 has an input circuit coupled across the unregulated source 10 and an output circuit 101. The network 100 may be of conventional design for rectifying the A.C. voltage from the source 10 and comparing the rectified voltage with a reference voltage to provide a D.C. output voltage across the output circuit 101 of constant or controlled magnitude. A transistor switching circuit 102 is provided for converting the direct current voltage from the network 100 into a square wave signal of controlled amplitude. The switching circuit 102 includes a pair of p-n-p junction transistors 103 and 104 which are illustrated by the conventional symbols. A primary winding 105 of a transformer 106 is connected to the collector electrodes of the transistors 103 and 104 as shown. The output circuit from the voltage reference network 100 is coupled to a center tap 107 of the primary winding 105 and to the emitter electrodes of the transistors as shown to provide the operating voltage for the transistors and control the amplitude of the square wave as will be described.

The base electrodes of the transistors 103 and 104 are connected to an output circuit 108 of a phase control network 109. The phase control network 109 includes a pair of capacitors 110 and 111 connected in series with an inductor 112, a variable resistor 113 and a resistor 114. Another inductor 115 is connected between the resistor 114 and capacitor 110 as shown. The output circuit 108 of the network 109 is coupled across the capacitor 111 and the inductor 112. The variable resistor 113 controls the phase shift between the A.C. signal in the output circuit 108 and the A.C. signal of the source 10.

To provide the proper operating bias for the transistors of the switching circuit 102 a pair of resistors 117 and 118 are connected between the emitter and base electrodes of the transistors 103 and 104 as shown. A pair of diodes 120 and 121 are connected in series across the base electrodes of the transistors with the cathodes of the diodes being connected together to control the maximum base emitter voltages applied to the transistors 103 and

104. The transistor switching circuit is arranged so the transistors are alternately switched on and off by the A.C. voltage output of the phase control network 109 to provide a square wave signal in the primary winding 105 of the transformer 106. This square wave signal is applied to a square wave-to-sine wave filter 125 by a secondary winding 105' of transformer 106. The filter 125 includes an inductor 126, a capacitor 127, an inductor 128, a resistor 129 and a resistor 130 connected in series across the secondary winding 105 in that order. A capacitor 131 is connected between inductor 126 and the resistor 130 as shown. The filter 125 includes an output circuit 132 coupled across the resistor 129 which provides a sine wave voltage having an amplitude controlled by the square wave signal generated in the secondary winding 105 in the transformer 106.

There has thus been described a simple stabilization circuit for controlling an output voltage in accordance with the waveform, amplitude and frequency of a reference signal. The voltage stabilizer of this invention unlike conventional prior art closed loop regulators is of the open loop type. In the voltage control circuit of this invention the stabilized output voltage is a function only of the reference signal and is not dependent upon the detection of an error signal in the output circuit or a closed loop feedback circuit.

Various modifications of the invention will be obvious to those skilled in the art. For example, the reference signal generator could provide an output signal of any predetermined waveform such as a square wave, a triangular wave, etc. Also the power for operating the amplifiers 52 and 70 could be derived from a separate source.

I claim:

1. In a voltage control circuit for supplying a regulated output signal to a load through a pair of leads from an unregulated output voltage source the combination which comprises, reference signal generating means for generating an alternating current reference signal, signal coupling means having a first winding connected across said reference signal generating means and a second winding having two terminals and inductively coupled to said first winding, amplifying means having a two-terminal input circuit and an output circuit, means connecting one terminal of said input circuit of the amplifying means to one terminal of said second winding, and means for direct current connecting the other terminal of said second winding to one lead of said pair of leads, load current sensing means coupled in series with the source for producing an output signal representative of the current flow through the load, resistive means connected to said load current sensing means and direct current connected in series between the remaining terminal of said input circuit and said other lead for applyig the output signal from the load sensing means to said amplifying means, a pair of output terminals, means for coupling the output circuit of the amplifying means and the source in series relationship across the output terminals to provide an output signal across said output terminals which is directly compensated for losses from said output coupling means and is proportional to the reference signal.

2. The combination as defined in claim 1 wherein the load current sensing means includes a current transformer connected in parallel with said resistive means, said transformer being operative for measuring the load current.

3. In a voltage control circuit for supplying three-phase regulated output signals to a load from a three-phase unregulated output voltage source the combination which comprises reference signal generating means having a three-phase output circuit for generating a three-phase reference signal of predetermined electrical characteristics in the output circuit thereof, differential amplifying means having a pair of three-phase input circuits and a three-phase output circuit, means for connecting respective input circuits of the differential amplifying means across the source, means for connecting the other respective input circuits of the amplifying means across the output circuits of the reference signal generating means, load current sensing means coupled in series with each phase of the source for producing an output signal representative of the current flow through the respective phases of the load, means for coupling the output signal from the load sensing means to respective input circuits of the amplifying means, three-phase output terminals and means for connecting the respective phases of the output circuit of the amplifying means and the source in series relationship across the output terminals for providing three-phase output signals across the output signals which is directly proportional to the reference signal.

4. In a voltage control circuit for supplying a stabilized signal from an unregulated output voltage source through a pair of leads to a pair of load terminals, a reference signal generating means for generating an alternating current reference signal, differential amplifying means having an output circuit and a two-terminal input circuit, a transformer having a primary winding connected across said reference signal generating means and a secondary winding inductively coupled to said primary winding, means direct current connecting said secondary winding between one terminal of said two-terminal input circuit and one lead of said pair of leads for applying an input signal to said amplifying means which is proportional to the instantaneous difference between said unregulated voltage of said source and said reference signal, means for coupling said output circuit of said amplifier means to one of said load terminals and in a series circuit with said unregulated source and the other load terminal; the improvement comprising load current sensing means including a resistor connected to the other terminal of said two-terminal input circuit and direct current connected to the other of said leads intermediate said source and said output coupling means, and further including a current transformer inductively coupled to said other lead and connected in parallel across said resistor for adding to said above claimed input signal a coupling loss compensating signal representative of the current flow through said load terminals.

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