Aug. 3, 1965 E. B. HILKER 3,199,020

VOLTAGE CONTROL DEVICE

Filed July 5, 1961

FIG. 1

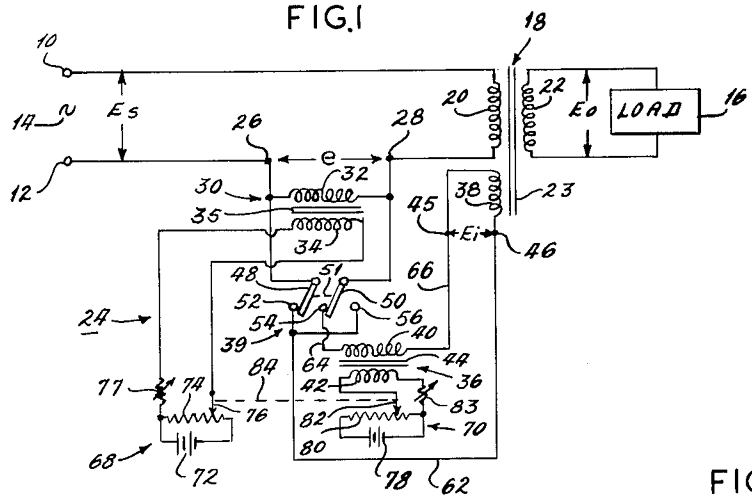


FIG. 2

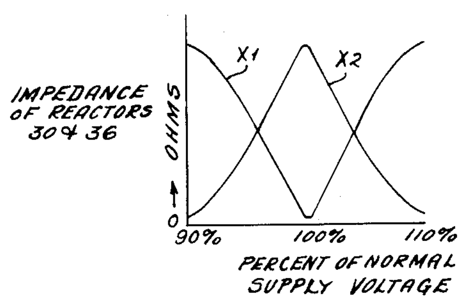
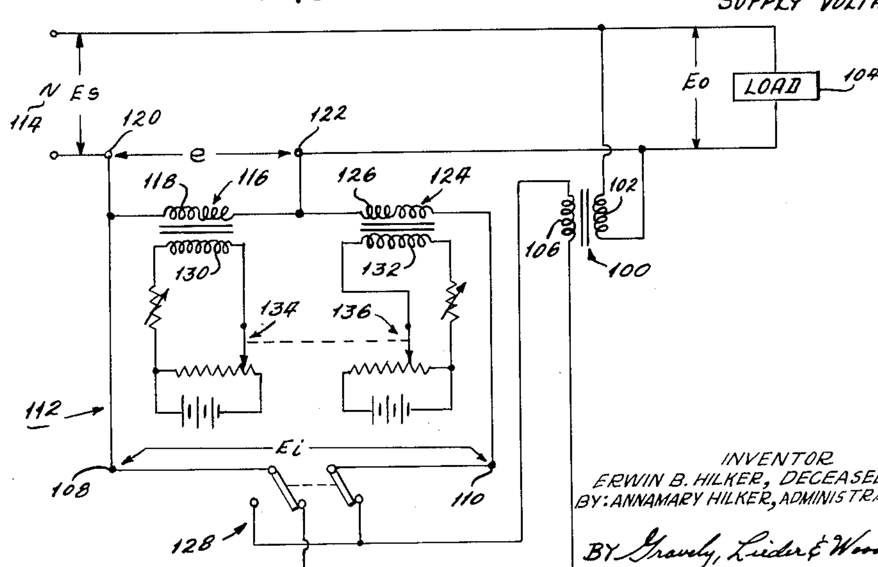


FIG. 3



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1

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VOLTAGE CONTROL DEVICE

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This invention relates to electrical control devices and more particularly to voltage control devices employing variable impedances for control.

The voltage of an electrical system is often controlled or regulated by a tap changing device associated with a tapped winding of a transformer; however, such equipment produces abrupt or stepped voltage changes. Variable impedances, such as saturable core reactors, have been used in control devices to vary or regulate voltage in a smooth or stepless manner, but the cost of the impedances, especially when used in higher voltage systems, has been considerable. Also, some such saturable core reactor control arrangements produce undesirable phase shift effects because of their reactance, and in many cases, the saturation of the reactor cores produce undesirably high harmonic voltages in the system.

It is therefore a general object of the present invention to provide a voltage control device employing variable impedances and which substantially avoids or overcomes to a large degree the abovementioned disadvantages.

Another object of the present invention is to provide a variable voltage producing control device employing variable impedances for control and which is especially economical.

Another object is to provide a voltage control device employing saturable reactors wherein the number of reactors and the cost of each are substantially reduced.

Another object is to provide a voltage control device employing saturable reactors for controlling the voltage of a power supply system in a stepless manner and wherein phase shift and harmonic effects are held to a minimum.

Still another object is to provide a voltage control system employing a minimum number of saturable reactors in controlling the voltage of the system within a relatively large control range while the electrical design ratings, and therefore cost, of the reactors is relatively low.

In accordance with one form of the present invention, a voltage control device is provided which includes a first circuit having a variable impedance device, and a second circuit connected in parallel relation with the first circuit and which includes another variable impedance device in series with a shiftable phase or reversible polarity source of voltage. By selectively varying the impedances, and changing the phase or polarity of the voltage source, the voltage across the first named impedance can be varied over a substantial range.

These and other objects and advantages of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings.

In the drawings:

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

FIG. 2 is a graphical representation of the impedances of the controlled reactors of FIG. 1 plotted as a function of supply voltage, and

2

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

The circuit of FIG 1 includes a pair of power input circuit terminals 10 and 12 connected across an alternating current supply source 14 for supplying power to a load 16 through a transformer 18 having a primary winding 20 and a secondary winding 22 on a magnetic core 23. Connected in series circuit relation between the power input and output circuits is a voltage control device, indicated generally at 24, for controlling the power output or load voltage within predetermined limits.

In the illustrated embodiment shown in FIG. 1, the voltage control device 24 is connected between a pair of terminals 26 and 28, and in series with primary winding 20 and the voltage supply source 14. The control device includes a variable impedance device shown as a saturable core reactor 30 having a reactance winding 32 and a control winding 34 on a magnetic core 35. The reactance winding 32 is connected between the terminals 26 and 28 in series with the supply source 14 and primary winding 20. Connected in parallel circuit relation with the reactor 30 between the terminals 26 and 28 is a series circuit including a variable impedance, shown as a saturable core reactor 36, and an auxiliary source of voltage with means for reversing the polarity or vectorially shifting the phase of the voltage therefrom. The auxiliary source is shown in FIG. 1 as an auxiliary winding 38 on the core 23 connected with a reversing switch 39. Reactor 36 includes a reactance winding 40 and a control winding 42 on a magnetic core 44. The auxiliary winding 38 is connected through the reversing switch 39 and the series connected reactance winding 40 in a circuit across the reactance winding 32 of reactor 30. A pair of terminals 45 and 46, which are respectively connected to the opposite ends of winding 38, are referred to herein as the input terminals of the control device, while terminals 26 and 28 are referred to as the output terminals of the control device.

The reversing switch 39 is shown for illustration as a two-position switch including a pair of movable contact arms 48 and 50 which are movable in concert, as indicated by the dashed line connection 51, and three stationary contacts 52, 54, and 56. In the switch operating position shown in FIG. 1, the contact arms 48 and 50 are in engagement with contacts 52 and 54, respectively. When the switch is actuated to its other operating position, the contact arms 48 and 50 are in engagement with contacts 54 and 56, respectively. The stationary contacts 52 and 56 are connected together and they are connected by a lead 62 to one side of the auxiliary winding 38. The center contact 54 is connected to the other side of winding 38 by a lead 64, the reactance winding 40, and a lead 66. With the switch 39 connected in this manner, the phase or polarity connections of auxiliary winding 38 can be reversed with respect to the terminals 26 and 28.

The impedances of the reactors 30 and 36 are varied by passing control current through the reactor control windings 34 and 42 which varies the saturation of the reactor cores 35 and 44. While various control circuits may be employed to supply control current to each of the control windings 34 and 42, simple, mechanically controllable, direct current sources, indicated generally at 68 and 70, are shown in the drawings for illustration. The control source 68 includes a battery 72 connected across a potentiometer 74 which has a movable arm 76 connected to one side of the control winding 34, and one end of the potentiometer is connected through and adjustable resistance 77 to the other side of the control winding 34. Similarly, the control source 70 includes a battery 78 connected across a potentiometer 80 having a movable arm 82 connected to one side of control winding 42, and one end of the potentiometer is connected to the other side of the winding 42 through an adjustable resistor 83. The movable potentiometer arms 76 and 82 are shown coupled together for concert movement, as indicated by a dashed line connection 84. As will be apparent from the circuit of FIG. 1, movement of the potentiometer arms 76 and 82 to the left will decrease the direct current in control winding 34 and increase the direct current flowing in control winding 42. Movement of the potentiometer arms in the opposite direction or to the right will, of course, increase the current in winding 34 and decrease the current in winding 42. In this way, the control currents flowing in the reactor control windings can be varied inversely with respect to each other to thereby vary the reactances of reactance windings 32 and 40 inversely with respect to each other.

In the following discussion of the operation of the circuit of FIG. 1, it will be assumed that the control device 24 is operated in a manner to maintain the power output or load voltage substantially constant even though the voltage of supply source 14 varies above and below its normal or predetermined value. In describing the operation of the system, the auxiliary winding 38 is considered as functioning as another secondary winding to supply an input voltage E_i across the input terminals 45 and 46 of the control device 24 to thereby provide a variable phase adjusting voltage e across the control device output terminals 26 and 28. By controlling the reactance values and selectively operating the reversing switch 39, the voltage e can be varied so that it effectively aids or opposes the supply voltage E_s, or is substantially ineffectual, to maintain the power output or load voltage E_o at or return it to its predetermined normal value. For purpose of illustration, the winding 38 will be assumed to have a number of turns equal to 10% of the number of turns of primary winding 20 so that the voltage e between terminals 26 and 28 is effectively variable within the range of from minus 10% to plus 10% of the normal value of supply voltage E_s, as will be more fully explained hereinafter.

In FIG. 2, curves X_1 and X_2, respectively, represent the impedance values of the reactance windings 32 and 40 of saturable reactors 30 and 36 over the voltage range of control device 24. As indicated by curves X_1 and X_2, the impedance of reactance windings 32 and 40 are varied inversely with respect to each other. When the supply voltage is at 100% of its normal value, the impedance of winding 32 is at a low or minimum value and the impedance of winding 40 is at a high or maximum value. As the supply voltage decreases or increases from its normal value, the impedance of winding 32, curve X_1, increases while the impedance of winding 40, curve X_2, decreases. When the supply voltage is at 90% or 110% of its normal value, the impedance of winding 32 is at a high or maximum value and the impedance of winding 40 is at a low or minimum value. The effects of varying the impedances or reactors 30 and 36 will be more apparent from the following example of operation.

In considering the operation of the circuit of FIG. 1, the supply of voltage E_s and the load voltage E_o will be considered to be at their respective normal values when the switch 39 is in the position shown in FIG. 1 and the potentiometers 74 and 80 are adjusted to provide a high or maximum D.C. current in control winding 34 and a low or minimum D.C. current in control winding 42. Under these conditions, reactor 30 will be substantially saturated and the impedance of reactance winding 32 at a minimum value while the reactor 36 will be unsaturated and

the impedance of winding 40 at a maximum value. Substantially all the control device input voltage E_i will appear across the reactance winding 40, and since the reactance of winding 32 is at a minimum value the adjusting voltage e will be substantially zero. The load voltage will be at its predtermined value as determined by the supply voltage value and turns ratio between the primary 20 and secondary 22. If the impedance of winding 32 could be reduced to zero when the supply and load voltages are at their normal values, there would be, in effect, a short circuit across the terminals 26 and 28 and the adjusting voltage e would be zero.

If the supply voltage E_s increases from its normal value to a value above normal, the potentiometer arms 76 and 82 are moved to the left, as viewed in FIG. 1, to thereby decrease the D.C. current flowing in control winding 34 and increase the D.C. current in control winding 42. Varying the control current in this manner increases the impedance of reactance winding 32 and decreases the impedance of reactance winding 40. An adjusting voltage e will now appear across reactance winding 32 and terminals 26 and 28, and will be in phase opposition with the supply voltage E_s so that the load voltage E_o is maintained at or brought back to its normal value. For example, if the supply voltage E_s increased to 110% of its normal value, the impedance of winding 32 would be increased to a high or maximum value and the impedance of winding 40 decreaesd to a low or minimum value so that the auxiliary winding 38 would supply substantially the full voltage E_i (10% of the normal supply voltage) across terminals 26 and 28 in phase opposition or "bucking" relation with the supply voltage E_s. If the supply voltage now returns to its normal value, the potentiometer arms 76 and 82 are moved to the right to their original positions so that the adjusting voltage e is again at its minimum or substantially zero value.

On the other hand, if the supply voltage decreases from its normal value, the switch 39 is first operated to reverse the polarity connections of auxiliary winding 38 to thereby vectorially shift the phase of the adjusting voltage e with respect to the supply voltage E_s. By operating the switch from the position shown to its other position, input terminal 45 is connected through reactance winding 40, contact 54, and switch arm 48 to terminal 26, while input terminal 46 is connected through contact 56 and switch arm 50 to terminal 28. The switch is operated from one position to the other when the reactance winding 32 is at a relatively low or minimum impedance value, the voltage e being substantially at zero value and the supply and load voltages being substantially at their normal values. In this way, substantially all of the supply current is flowing through reactance winding 32 and substantially none through the switch when the switch is operated.

After the switch 39 is operated as indicated above, the potentiometer arms are moved to the left to increase the impedance of reactance winding 32 and decrease the reactance of winding 40. This again produces an adjusting voltage e across terminals 26 and 28 but, under these conditions, the voltage e is in aiding relation with the supply voltage E_s to thereby maintain the load voltage E_o at or raise it to its normal value. If the supply voltage, for example, should decrease to 90% of its normal value, the impedance of reactance winding 32 is adjusted to a high or maximum value while the impedance of reactance winding 40 is decreased to a minimum value to thereby provide an adjusting voltage e which is substantially 10% of the normal value of supply voltage and which is in the aiding or "boosting" direction.

While the circuit of FIG. 1 has been explained from a standpoint of having the voltage e appearing across circuit terminals 26 and 28 superposed on or injected into the supply voltage circuit in series "aiding" or "opposing" relationship, it can be described, of course, from the standpoint of varying the "effective ampere turns" on the primary side of transformer 18. From the latter point of view, current from supply source 14 is considered to flow through the auxiliary winding in a direction relative to the direction of current in the primary 20 to provide variable aiding ampere-turns or opposing ampere-turns depending upon the position of switch 39.

By utilizing the reversing switch 39 to reverse the polarity or vectorially shift the phase of the voltage impressed across the reactor 30, the same auxiliary winding 38 can be used to provide both "bucking" and "boosting" voltage effects, and only two reactors are necessary for providing this control. Also, each of the reactors may be designed only for the voltage of winding 38. For example, when either of the reactors 30 and 36 is saturated, the voltage across the other reactor is substantially equal to that of winding 38 or the voltage E_i. Since the reactors may be designed only for the voltage of auxiliary winding 38, the voltage rating and size, as well as cost of each reactor, is relatively low.

In addition, the total reactance in the power circuit of the system, i.e., the total series reactance presented by the reactors 30 and 36 is relatively low. For example, when the supply voltage is at its normal value, in the illustrated example of operation, reactor 30 is at a very low value, and when the supply voltage is at 90% and 110% of its normal value the other reactor 36 presents a low reactance to load current flow. Because of the relatively low average reactance to load current, the phase shift between supply and load voltages is relatively low. For the same reason, harmonic voltages, often generated by core saturation, are relatively low in the circuit hereinbefore described.

While the control device input voltage E_i in the illustrated embodiment is obtained from the auxiliary winding 38 disposed on the same core with the primary and secondary windings of transformer 18, other sources of voltage may be used. For example, instead of auxiliary winding 38, a separate transformer may be employed having a primary winding connected across the load 16 or supply source 14 and a secondary winding connected across input terminals 45 and 46.

In the modified construction shown in FIG. 3, a separate transformer 100 is utilized to provide the input voltage E_i to a control device. Transformer 100 has a primary winding 102 connected across a load 104 and a secondary winding 106 connected to a pair of input terminals indicated at 108 and 110 of a voltage control device 112. The control device 112 is connected in series circuit relation between a power supply source 114 and the load 104.

The control device 112 is somewhat similar to the control device 24 in FIG. 1. As seen in FIG. 3, a saturable reactor 116 has its reactance winding 118 connected between output terminals 120 and 122 of the control device in series circuit relation between the supply source 114 and load 104. A series circuit, which includes another saturable reactor 124 having a reactance winding 126 in series with the secondary winding 106, is connected between the terminals 120 and 122 across the reactance winding 118. A reversing switch 128 is connected between the winding 106 and the reactors for vectorially shifting (180°) the voltage from winding 106 or input voltage E_i with respect to the supply source voltage E_s. When the reversing switch 128 is operated, it reverses the polarity connections of winding 106 and shifts the phase of the variable adjusting voltage *e* developed across terminals 120 and 122.

Reactors 116 and 124 are provided with control windings 130 and 132, respectively, which are connected to be supplied with D.C. control current for varying the impedance of their associated reactance windings. As seen in FIG. 3, control windings 130 and 132 are connected to D.C. control sources 134 and 136, respectively. Each of the control sources are shown as including potentiometers and batteries with the arms of the potentiometers interconnected for concert movement, as in the circuit of FIG. 1.

The operation of the circuit of FIG. 3 is similar to that described in connection with the circuit of FIG. 1. By varying the currents in control windings 130 and 132 inversely with respect to each other, the impedances of reactance windings 118 and 126 vary inversely with respect to each other to thereby vary the adjusting voltage *e* across terminals 120 and 122. The adjusting voltage *e* is combined with the supply voltage E_s to control or regulate the load voltage E_o. As previously mentioned herein with regard to the circuit of FIG. 1, the variable adjusting voltage *e* can be controlled to provide a voltage "boosting" or a voltage "bucking" effect depending upon the position of the reversing switch. The impedances of reactance windings 118 and 126 may be varied in the manner shown in FIG. 2. In such case, the curve X_1 would represent the impedance values of winding 118 and curve X_2 the impedance values of winding 126 over the voltage control range of the control device. The switch 128 is operated from one position to its other position when the reactance of winding 118 is low or at a minimum value and is carrying substantially the full load current.

While the voltage control device in each of the illustrated embodiments is conductively coupled into the power circuit by direct connection, a coupling transformer (not shown) may be used. In such case, the primary of the coupling transformer may be connected across the reactor 30 in FIG. 1, or the reactor 116 in FIG. 3, and the secondary connected in series in the power circuit.

It is to be understood that the foregoing description and the accompanying drawings have been given only by way of illustration and example, and that changes and alterations in the present disclosure, which will be readily apparent to one skilled in the art, are contemplated as within the scope of the present invention which is limited only by the claims which follow.

What is claimed is:

1. A voltage control device comprising a first circuit including a first variable impedance device, a second circuit coupled across said first circuit and including a second variable impedance device, means for connecting a source of voltage in said second circuit to provide a voltage across said first circuit, means for selectively reversing the phase of said voltage, and means for varying the impedance values of said impedance devices to vary the magnitude of said voltage.

2. A voltage control device comprising a first variable impedance device, a series circuit including a voltage source and a second variable impedance device coupled in parallel circuit relation with said first impedance device, means for inversely varying the impedance values of said impedance devices to provide a variable voltage across said first variable impedance device, and means operable to reverse the phase of said variable voltage.

3. In combination, a power output circuit, a power input circuit connected to a first source of supply voltage to supply power to the power output circuit, and a voltage control device for varying the voltage supplied to said power output circuit comprising a first variable impedance device coupled in series circuit relation with one of said power circuits, a series circuit including a second variable impedance device and a second source of voltage coupled in parallel circuit relation with said first impedance device, means for varying the impedance values of said impedance devices to provide a variable voltage across said first impedance device, and switch means in said series circuit for selectively connecting said second source of voltage in either aiding or opposing relation with respect to the voltage of said first source of voltage.

4. A voltage control device comprising a first circuit including a first variable impedance device, a second

circuit connected across said first circuit and including a second variable impedance device, means for connecting a source of voltage in said second circuit, means for varying the impedance values of said devices to provide a variable voltage across said first impedance device, and a mechanical reversing switch connected in said second circuit for selectivity reversing the phase of said variable voltage.

5. A voltage control device comprising a first variable reactance device device, a series circuit including a transformer winding and a second variable reactance device coupled in parallel circuit relation with said first reactance device, means for energizing said winding to provide voltage of predetermined phase in said series circuit, means for varying the reactance values of said reactance devices, and means for shifting the phase of said voltage 180°.

6. A voltage control device comprising a pair of saturable reactors each having a reactance winding and a control winding, a series circuit including a source of voltage of predetermined phase and the reactance winding of one of said reactors, said series circuit being coupled in parallel circuit relation with the reactance winding of the other of said reactors, means for supplying variable control current to each of the control windings of said reactors to provide a variable voltage across the reactance winding of said other reactor, and additional means operable to shift the phase of said variable voltage.

7. An electrical system comprising a power input circuit connectable to a source of supply voltage for supplying power to a power output circuit, a first circuit including a first saturable reactor coupled in series circuit relation with one of said power circuits, a second circuit including a second saturable reactor coupled in parallel circuit relation with said first circuit, means for connecting an auxiliary source of voltage of predetermined phase in said second circuit, means for varying the reactance values of said reactors inversely with respect to each other, and additional means for shifting the phase of the voltage from said auxiliary source with respect to said supply voltage.

8. An electrical control device comprising a first circuit including a first saturable reactor, a second circuit including a second saturable reactor and a transformer winding connected in series, said second circuit being coupled across said first circuit, means for varying the reactances of said first and second reactors, and a mechanical reversing switch connected in said second circuit for selectively reversing the phase connections of said winding.

9. An electrical system comprising a power input circuit connectable to an alternating current source of supply voltage for supplying power to a power output circuit, a first saturable reactor coupled in series circuit relation between said power circuits, a series circuit including a transformer winding and a second saturable reactor coupled in parallel circuit relation with said first saturable reactor, means for energizing said winding to provide a voltage across said first saturable reactor, a mechanical reversing switch in said series circuit operable to reverse the phase connections of said winding in said series circuit, and means for varying the reactance values of said reactors.

10. An alternating current supply system comprising power input and output circuits, a transformer having a main winding coupled across one of said power circuits, and an auxiliary winding coupled to said main winding, and a control circuit comprising a first circuit including a first reactor coupled in series with said main winding, a second circuit including a second reactor connected in series with said auxliary winding, and a reversing switch for selectively reversing the phase of the voltage from said auxiliary winding, said second circuit being coupled in parallel relation with said first circuit, and means associated with said reactors for varying the reactance thereof.

11. An alternating current control system comprising a transformer having a main primary winding connected to an alternating current supply source, a main secondary winding connected to a load circuit, and an auxiliary winding, and a voltage control device comprising a first circuit including a first saturable reactor coupled in series circuit relation with one of said main windings, a second circuit including a second saturable reactor and said auxiliary winding connected in series therewith, said second circuit being connected in parallel circuit relation with said first circuit, a reversing switch connected with said auxiliary winding for selectively reversing the phase relationship of said auxiliary winding with respect to said primary winding, and means for inversely varying the reactances of said reactors.

12. An A.C. power supply system comprising power input and output circuits, means for connecting said power input circuit to an A.C. voltage supply source for supplying power to said power output circuit, and a voltage control circuit for controlling the voltage supplied to said power output circuit comprising a first saturable core reactor having a reactance winding and a control winding, a first circuit having end terminals and including the reactance winding of said first reactor connected between said end terminals, means connecting said first circuit in series circuit relation with said power input and output circuits, a second circuit including a second saturable core reactor having a reactance winding and a control winding, an auxiliary A.C. voltage supply source, and means including a phase reversing switch having first and second switch positions connecting the reactance winding of said second reactor in series circuit relation with said auxiliary source across said first circuit between said end terminals, said switch when in said first switch position connecting one of said end terminals through the reactance winding of said second reactor to one side of said auxiliary source and the other of said end terminals to the other side of said auxiliary source, said switch when in said second switch position connecting said one end terminal to said other side of said auxiliary source and said other end terminal through the reactance winding of said second reactor to said one side of said auxiliary source, means for supplying control current to each of said control windings, and means for inversely varying the magnitudes of the control currents flowing in said control windings for inversely varying the reactance values of said reactance windings to provide a variable A.C. voltage across said first circuit.

13. An A.C. power supply system comprising a power input and output circuits, means for connecting said power input circuit to an A.C. voltage supply source for supplying power to said power output circuit, and a voltage control circuit for controlling the voltage supplied to said power output circuit comprising a first saturable core reactor having a reactance winding and a control winding, a first circuit having first and second circuit terminals and including the reactance winding of said first reactor connected between said circuit terminals, means connecting said first circuit in series circuit relation with said power input and output circuits, a second circuit including a second saturable core reactor having a reactance winding and a control winding, a transformer having a transformer winding with end terminals, means for energizing said transformer winding to provide a voltage thereacross, and means including a phase reversing switch having first and second switch positions connecting the reactance winding of said second reactor in series circuit relation with said transformer winding across said first circuit between said circuit terminals, said switch when in said first switch position connecting said first and second circuit terminals to said first and second end terminals, respectively, with the reactance winding of said second reactor connected between one of said circuit terminals and one of said end

terminals, said switch when in said second switch position connecting said first and second circuit terminals to said second and first end terminals, respectively, with the reactance winding of said second reactor connected between one of said circuit terminals and one of said end terminals, means for supplying control current to each of said control windings, and means for inversely varying the magnitudes of the control currents flowing in said control windings for inversely varying the reactance values of said reactance windings to provide a variable voltage across said first circuit to control the voltage supplied to said power output circuit.

No references cited.

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