

April 5, 1960

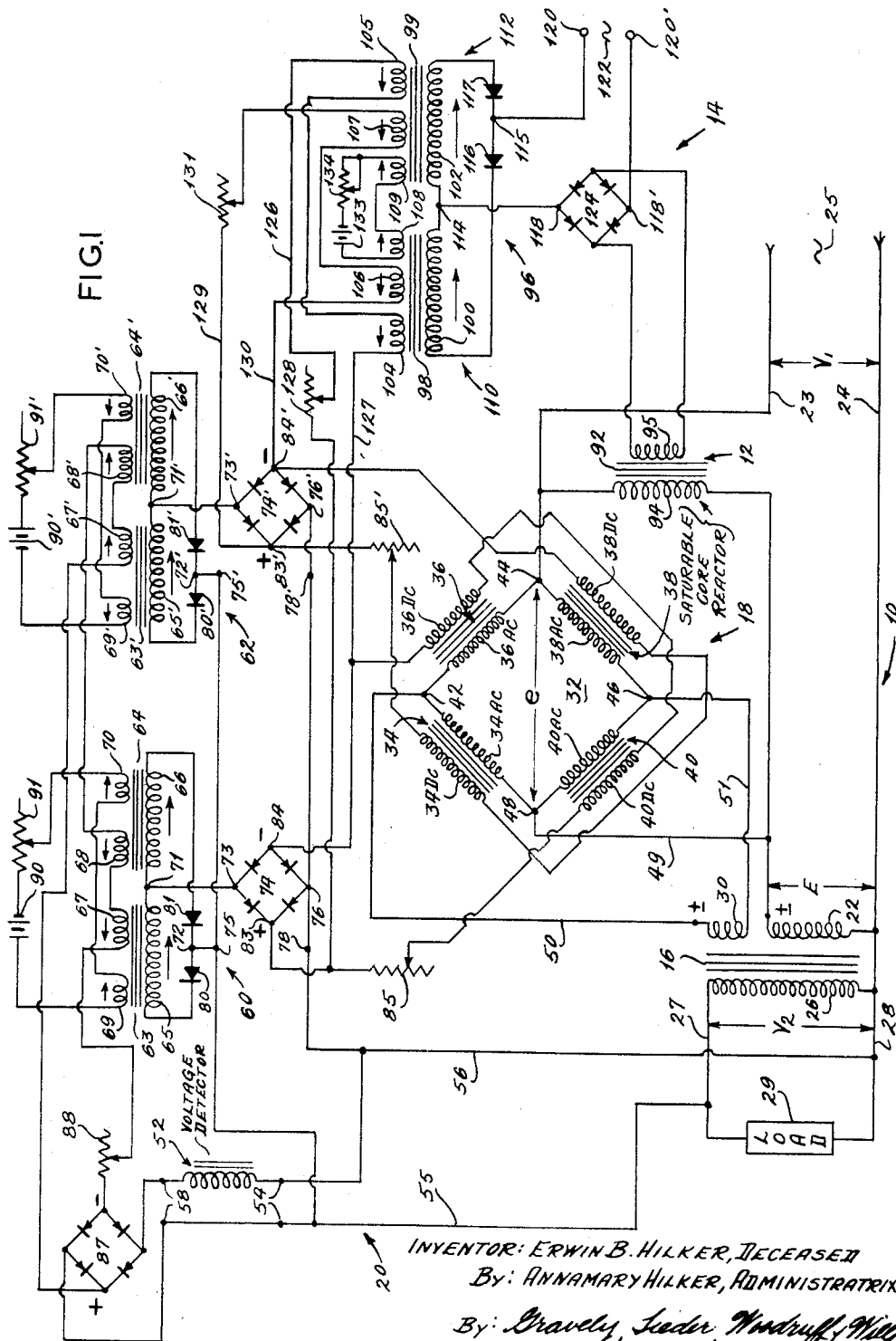
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2,931,968

CONTROL FOR HARMONIC SUPPRESSOR

Filed Sept. 30, 1957

3 Sheets-Sheet 1



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FIG. 2

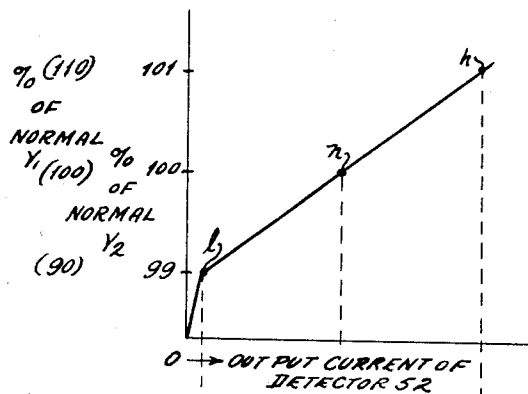


FIG. 5

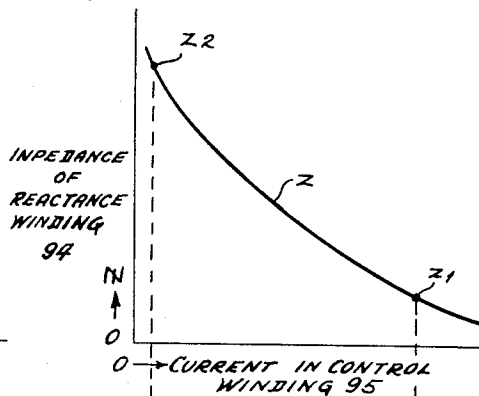


FIG. 3

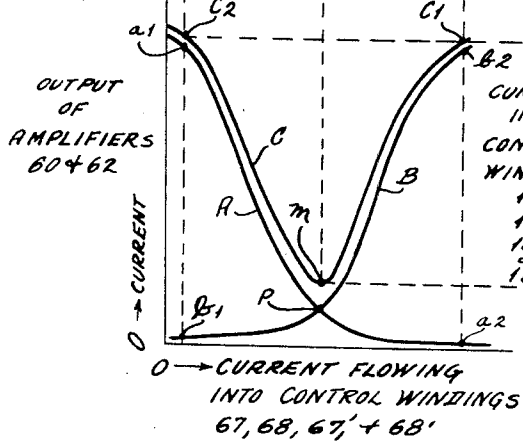
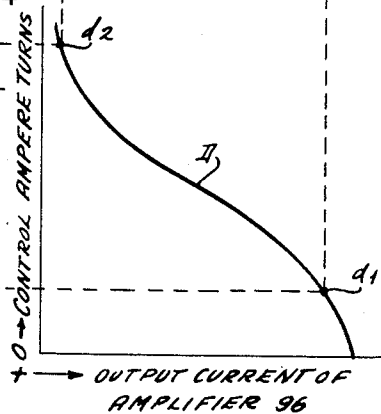


FIG. 4



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FIG.6

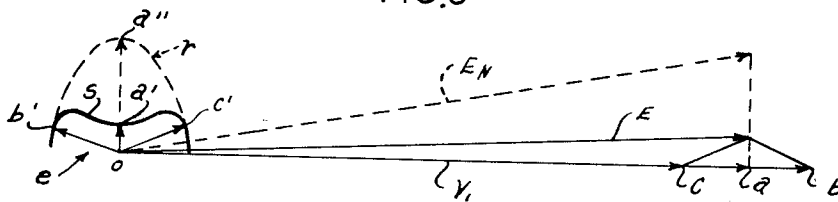
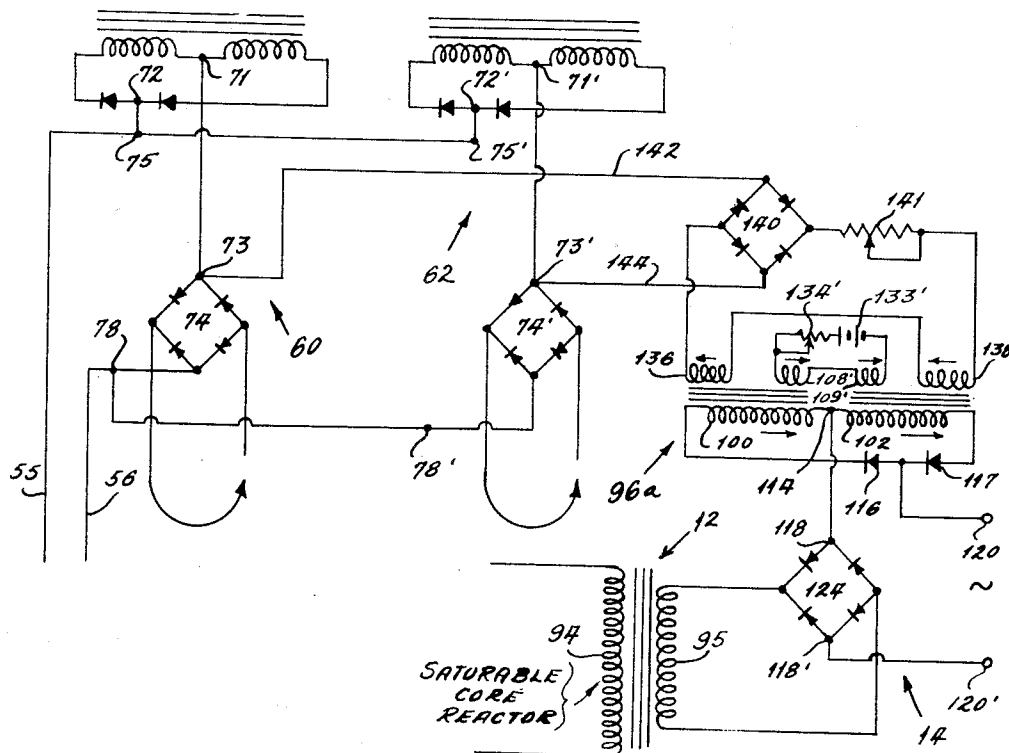


FIG.7



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2,931,968

CONTROL FOR HARMONIC SUPPRESSOR

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Application September 30, 1957, Serial No. 687,084

24 Claims. (Cl. 323-66)

The present invention relates generally to the voltage control art and more particularly to novel automatic control means in combination with a harmonic and phase shift suppressor of the type shown and described in copending application, Serial No. 680,342, filed August 26, 1957, for use with a voltage control device of the type shown and described in copending application, Serial No. 429,465, filed May 13, 1954, and J. S. Malsbary Patent No. 2,892,146, issued June 23, 1959.

A voltage control device of the type disclosed in the aforementioned applications includes means for providing a variable compensating or adjusting voltage which is superposed on, or injected into, either the input or output voltage of a transformer so as to maintain the output voltage of the transformer at substantially the desired value regardless of change in the supply voltage within predetermined limits. The compensating voltage is developed in a bridge circuit, as for example, a Wheatstone type bridge circuit of four saturable core reactors whose impedances are made responsive to selected external conditions such as voltage or current; the magnitude and phase of the compensating voltage being determined by the relative impedance values of the arms of the bridge.

Although the aforementioned control device has operated very satisfactorily, it has been found that under certain operating conditions the output voltage contains so-called higher harmonics which may interfere with telephonic communications; also, there is at times an undesirable phase shift between the supply and output voltages.

The harmonic and phase shift suppressor, disclosed in the abovementioned application, Serial No. 680,342 substantially eliminates the harmonic components otherwise present in the output voltage, and maintains the phase shift between supply voltage and output voltage small and substantially constant. In the last mentioned application, the suppressor means comprises a variable impedance device (shown in the preferred embodiment as a saturable core reactor) connected across the bridge circuit in which the compensating voltage is developed; with means for manually controlling the impedance of the reactor.

The present invention concerns a phase shift and harmonic suppressor and means for automatically controlling the suppressor in response to preselected conditions. Briefly, the present invention comprises a variable impedance device connected across the bridge circuit in which the variable voltage is developed, and means for automatically varying the impedance of the device in response to variations in an electrical condition to be controlled whereby the impedance of the device is relatively low when the electrical condition is at a predetermined desired value, and relatively high when the electrical condition varies from the desired value.

It is an object of the present invention to provide novel control means for automatically controlling a harmonic and phase shift suppressor of the aforementioned

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type. More particularly, it is an object to provide such control means which are responsive to the variations in selected electrical conditions in the circuit, as for example, voltage and current values.

Another object is to provide an electric control system of the aforementioned type wherein the output voltage of the system is automatically maintained substantially free of harmonic components.

Another object is to provide an electric control system of the aforementioned type wherein the phase shift between the supply voltage and output voltage of the system is automatically maintained small and substantially constant.

Another object is to provide a novel fully automatic voltage control system having a controlled saturable core reactor bridge providing a compensating voltage for maintaining an electrical condition of the system substantially constant, wherein the phase shift between the supply voltage and output voltage of the system is maintained small and the harmonic components otherwise present in the output voltage are greatly reduced.

Further objects and advantages of the present invention will be apparent from the detailed description, reference being had to the accompanying drawings wherein preferred embodiments of the present invention are shown.

In the drawings:

Fig. 1 is a schematic diagram of a preferred embodiment of the present invention,

Fig. 2 is a graph of the characteristic curve of the voltage detector 52 of Fig. 1,

Fig. 3 is a chart containing the control characteristic curves of each of the amplifiers 60 and 62 of Fig. 1, and a curve representing a resultant of these curves,

Fig. 4 is a chart containing the control characteristic curve of the amplifier 96 in Fig. 1,

Fig. 5 is a chart containing the impedance curve of the suppressor reactor 12 of Fig. 1,

Fig. 6 is a vector diagram illustrating the phase relationship between the various transformer voltages both with and without benefit of the present invention, and

Fig. 7 is a partial schematic diagram illustrating a modified embodiment of the suppressor control.

Referring to the drawings and particularly to Fig. 1, there is shown for illustration an automatic voltage control device 10 which is of the type shown and described in copending application, Serial No. 497,978. Shown in combination with the control device is a harmonic and phase shift suppressor 12, and suppressor control means 14 for automatically controlling the impedance of the suppressor 12.

The automatic voltage control circuit 10 includes a power transformer 16, a compensating voltage device 18, and control means 20 for automatically controlling the operation of the device 18 to maintain the output voltage V_2 of the transformer 16 substantially constant regardless of changes in supply voltage V_1 within predetermined limits. It will be assumed for purposes of illustration only, that the output voltage V_2 is held substantially constant while the supply voltage V_1 may vary within the range of $\pm 10\%$ of the normal or desired value.

The transformer 16 includes a primary winding 22 which is connected through the compensating voltage device 18 and power lines 23 and 24 to an A.C. voltage supply source indicated at 25, a secondary winding 26 which is connected to conductors 27 and 28 for supplying power to a load 29, and a corrector winding 30 which will be considered hereinafter.

The compensating voltage device 18 includes a Wheatstone type bridge circuit 32 shown as having four saturable core reactors 34, 36, 38 and 40 connected together to form the four impedance arms of the bridge. Each

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reactor has a saturable magnetic core on which is positioned an alternating current reactance winding, and a direct current control winding for controlling the magnetic saturation of the core and the impedance of the A.C. winding. The windings of each reactor are identified in the drawing by corresponding like numerals with the letters AC or DC added thereto.

The windings 34AC and 36AC are connected together at a corner 42, the windings 36AC and 38AC are connected together at a corner 44, the windings 38AC and 40AC are connected together at a corner 46, and the windings 40AC and 34AC are connected together at a corner 48.

The control windings 34DC and 38DC of the bridge circuit 32 are connected in series circuit relation, and a signal applied to this pair of series connected control windings will determine the impedance of the diametrically opposite reactance windings 34AC and 38AC. The control windings 36DC and 40DC are also connected in series circuit relation, and a signal applied to this pair of control windings will determine the impedance of the other diametrically opposite reactance windings 36AC and 40AC.

Although the bridge circuit 32 is shown including four separate cores with an A.C. reactance winding and a D.C. control winding on each core, other winding and core arrangements may be used if desired. For example, each set of diametrically opposite reactors may be combined into a single "twin reactor" unit containing a three-legged core provided with two A.C. reactance windings and a common D.C. control winding. Each of the outer legs would be provided with an A.C. winding while the center leg is provided with the common D.C. winding. In such a case, the bridge circuit contains two sets of saturable core reactors with each set combined into a "twin reactor."

A conductor 49 connects one end of the primary winding 22 to the corner 48 of the bridge circuit, and the diametrically opposite corner 44 of the bridge circuit is connected to the power line 23. The other diametrically opposite corners 42 and 46 are connected across the corrector winding 30 through the conductors 50 and 51, respectively.

The corrector winding 30 provides a voltage which is impressed across the corners 42 and 46 of the bridge circuit so as to provide a compensating or adjusting voltage "e" which appears across the other corners 44 and 48 of the bridge. It will be assumed for purpose of discussion, that the number of turns of the corrector winding is 10% of the number of turns of the primary winding 22 so that the voltage across the corrector winding is 10% of the induced voltage, thus permitting compensation for approximately a 10% change in the supply voltage. The compensating voltage "e" is effectively in series with the primary winding voltage E, and, depending upon the balance conditions or relative impedances of the two pairs of diametrically opposite reactors of the bridge circuit, the voltage "e" is either substantially ineffectual, aiding, or opposing the supply voltage V_1 , to thereby affect the induced voltage E in such manner as to maintain the magnitude of the output voltage V_2 substantially constant at the desired or normal value.

In the illustrated embodiment of Fig. 1, the control circuit 20 automatically controls the balance conditions of the saturable core reactor bridge 32 by supplying control signals (responsive to the small variations in the controlled output voltage V_2) to the D.C. control windings of the reactors of the bridge circuit. The control circuit 20 includes a voltage detector 52 having a pair of input terminals 54 shown connected across the output circuit of the transformer 16 through conductors 55 and 56, and a pair of detector output terminals 58 connected to supply control signals to a pair of amplifiers 60 and 62. The output of these amplifiers supply the current to the D.C. control windings of the bridge.

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The amplifiers 60 and 62 shown in the drawing are self-saturating magnetic amplifiers of the well known type. The amplifier 60 includes two saturable magnetic cores 63 and 64 having thereon reactance or power windings 65 and 66 respectively, D.C. control windings 67 and 68 respectively, and D.C. bias windings 69 and 70, respectively. The power windings 65 and 66 are each connected in a branch circuit with the branches being connected in parallel between common junctions 71 and 72 of the two branches. The junction 71 is connected to an A.C. input terminal 73 of a full-wave bridge-type rectifier 74 while the junction 72 is connected to a terminal 75 which in turn connects with the conductor 55. Another A.C. input terminal 76 of the rectifier 74 is connected to a terminal 78 which in turn connects with the conductor 56. The terminals 75 and 78 form the A.C. power input terminals of the amplifier while the terminals 73 and 76 form the A.C. power output terminals of the amplifier as well as the A.C. input terminals of the rectifier 74.

A one-way valve or half-wave rectifier 80 is connected in series with the power winding 65 and a half-wave rectifier 81 is connected in series with the power winding 66. The half-wave rectifiers 80 and 81 are oppositely related or poled with respect to a supply voltage applied to the amplifier power input terminals 75 and 78 so that the rectifiers conduct current on opposite half cycles of the power supply voltage, and provide an A.C. output at the amplifier output terminals 73 and 76. Thus, half-wave or intermittent unidirectional current flows in each of the power windings 65 and 66 generating unidirectional M.M.F.'s tending to saturate the cores and reduce the impedance of the power windings. The magnetic saturation resulting from these M.M.F.'s is referred to as self-saturation and the direction or sense of these M.M.F.'s as indicated by the arrows adjacent the power windings, is referred to as the saturating direction. M.M.F.'s in the opposite sense tend to increase the impedance of the power windings and are known as desaturating M.M.F.'s and the direction or sense of these M.M.F.'s is referred to as the desaturation direction. The relative directions of the M.M.F.'s resulting from current flowing in the various bias and control windings are indicated by arrows adjacent these windings.

In general, in an arrangement employing two separate cores per amplifier, each core carries one power winding and at least one control winding, while if the cores are close together or if the well known single three-legged core is employed, a single control winding may encircle both cores or the center leg of the three-legged core. In any case, the induced alternating current voltages or the alternating fluxes due to the pulsating current through each power winding are made to cancel out with respect to the control windings and bias windings if any are used.

The self-saturating amplifier 62 is similar to the amplifier 60 and like parts are identified by like numbers except that the numbers are primed. The A.C. power input terminals of both amplifiers are shown connected to the same power source, i.e., both are connected to the conductors 55 and 56 which in turn are connected across the output conductors 27 and 28 of the transformer 16.

The A.C. output current of the amplifier 60 is rectified by the full-wave rectifier 74 with D.C. output terminals 83 and 84 of the rectifier being connected to supply D.C. control currents to the reactor bridge control windings 36DC and 40DC through an adjustable resistance 85. The A.C. output current of amplifier 62 is rectified by the full-wave rectifier 74' with D.C. output terminals 83' and 84' of this rectifier connected to supply D.C. control currents to the reactor bridge control windings 34DC and 38DC through an adjustable resistance 85'.

The control windings 67, 68, 67' and 68' are connected in series and are connected to the D.C. output terminals of a fullwave rectifier 87 through an adjustable resistance 88. The A.C. input terminals of the rectifier 87 are

connected to the output terminals 58 of the voltage detector 52.

The control windings 67 and 68 are wound and connected so that current flow through these windings results in desaturating M.M.F.'s which tend to decrease the output of amplifier 60. The control windings 67' and 68', however, are wound and connected so that current flowing through them results in saturating M.M.F.'s which tend to increase the output of amplifier 62. Thus, the control windings are energized in response to the output of the voltage detector, and, as indicated by the arrows adjacent the control windings of each amplifier, the current supplied by the detector 52 causes the output current of one of the amplifiers to increase while the output of the other tends to decrease for a given change in current supplied by the detector.

The bias windings of each of the amplifiers are connected to any suitable current source. As illustrated in the drawing, the bias windings 69 and 70 of amplifier 60 are connected to a battery 90 through an adjustable resistance 91. The direction of bias current is such that the M.M.F. produced thereby is in the saturating direction as indicated by the arrows adjacent the windings 69 and 70. The magnitude of the bias current is so adjusted that when a small or zero signal is applied to the control windings 67 and 68 the output of the amplifier 60 is high or at its maximum value. The bias windings 69' and 70' of amplifier 62 are shown connected to be supplied from a battery 90' through an adjustable resistance 91', and the direction of bias current in these windings is such that the M.M.F. produced is in the desaturating direction as indicated by the arrows adjacent these windings. The magnitude of this bias current is so adjusted that when a small or zero signal is applied to the control windings 67' and 68' the output of amplifier 62 is low or at its minimum value.

The voltage detector 52 acts as a current regulating valve which does not permit an appreciable current to flow therethrough until the voltage applied to its input terminals 54 exceeds a predetermined critical value, and then the increase in current flow to its output circuit is in direct proportion to the increase in voltage above that critical value.

It will be assumed herein for illustration only that the output voltage V_2 is to be maintained within $\pm 1\%$ of the predetermined desired or normal value even though the supply voltage may vary from $+10\%$ to -10% of its normal value. Thus, in Fig. 2, there is shown a typical characteristic curve of the detector 52 in which the output current of the detector (going to the control coils 67, 68, 67' and 68') is along the abscissa axis and the output voltage V_2 , in percent of the normal value, is along the ordinate axis. There is also shown in parenthesis along the abscissa axis the corresponding supply voltage in percent of its normal value. It is seen from this curve that the detector has a low or negligible output current when the output voltage V_2 is at its minimum permissible value (99% of the normal value) and that the output current increases rapidly and substantially in proportion with an increase in output voltage V_2 above the minimum permissible value.

Any suitable voltage detector having a similar characteristic curve as that shown in Fig. 2 may be used. The detector 52, shown in Fig. 1, is of a well known type which consists simply of a coil wound on a saturable core and designed such that the core tends to saturate at a desired magnitude of voltage applied to it so that the current through the coil increases rapidly after saturation.

Referring to Fig. 3, the curve A represents the control characteristic of amplifier 60 (i.e., the output of amplifier 60 to coils 36DC and 40DC, based on the current flowing from the detector 52) and the curve B represents the characteristic curve of amplifier 62 (i.e., the output of amplifier 62 to coils 34DC and 38DC, based

on the current flowing from the detector 52). It will be noted that for a negligible or zero control current applied to the control windings 67, 68, 68' and 67' by the detector 52, the output of amplifier 60 is at a high or maximum value such as indicated by a point a_1 , on curve A, while the output of amplifier 62 is at a minimum value, such as indicated by a point b_1 , on curve B. As the output current of the detector increases from the negligible value, the output of amplifier 60 (curve A) decreases from the maximum value (point a_1) to a minimum value such as that at point a_2 , while the output current of amplifier 62 (curve B) increases from the minimum value (point b_1) to a maximum value such as that at point b_2 . Thus, it is seen from Figs. 2 and 3 that the output of amplifier 62 is directly proportional to the magnitude of the output voltage above the minimum permissible value, while the output of amplifier 60 is inversely proportional to the magnitude of output voltage above the minimum permissible value.

The two characteristic curves A and B are shown on the same graph (Fig. 3) and cross at a point "p" where the output current of each of the amplifiers is the same and at a relatively low value. The magnitude of the output of each amplifier being the same at point p, the two pairs of diametrically opposite reactors of the bridge 32 are equally energized and the bridge 32 is in balance. It will be apparent that the shape of the curves A and B and the location of the crossover point "p" can be varied, as for example, by changing the ratio of the current in the bias windings 69 and 70 with respect to the current in the bias windings 69' and 70'.

The operation of the complete voltage control device 10 is described in detail in the previously mentioned application Serial No. 497,978, and will only briefly be described herein.

When the output voltage V_2 is at its normal value, no adjusting or compensating voltage "e" is required. Therefore, when the output voltage V_2 is at 100% of its normal value (Fig. 2) the amplifiers 60 and 62 provide equal control currents (point p, Fig. 3) to the two pairs of diametrically opposite bridge reactors so that the bridge 32 is balanced. Thus, assuming that the voltage drops across the reactors in the bridge are equal and cophasal (a condition which will be discussed more fully hereinafter) the voltage across bridge corners 44 and 48 will be relatively low and substantially ineffectual with regard to the magnitude of the output voltage V_2 .

If the supply voltage V_1 increases above its normal value, the output voltage V_2 tends to increase, causing an increase in the output current of the detector 52 which, in turn, increases the output current of amplifier 62 while tending to decrease the output current of amplifier 60, as seen by the curves A and B in Fig. 3. The increase in output current of amplifier 62 tends to saturate the bridge reactors 34 and 38 so that the impedance of windings 34AC and 38AC decreases, while the decrease in the output current of amplifier 60 tends to increase the impedance of reactor windings 36AC and 40AC. Thus, the bridge circuit 32 is unbalanced and an adjusting voltage "e" appears across the terminals 44 and 48 of the bridge. This adjusting voltage "e" is of such magnitude and relative polarity or phase angle with respect to V_1 that it opposes or bucks V_1 , thereby reducing the primary or induced voltage E so as to compensate for the increase in V_1 and to maintain the output voltage V_2 substantially constant i.e., within its predetermined limits.

On the other hand, if the supply voltage V_1 decreases below the normal value, the output voltage V_2 tends to decrease, causing a decrease in the output of detector 52 which in turn causes an increase in the output of amplifier 60 while causing a decrease in the output of amplifier 62. The increase of output current of amplifier 60 tends to saturate the bridge reactors 36 and 40 and to reduce the impedance of windings 36AC and 40AC, while the decrease in output current of amplifier 62 tends

to increase the impedance of bridge reactor windings 34AC and 38AC. The bridge circuit, under these conditions, is again unbalanced and an adjusting voltage "e" appears across terminals 44 and 48 of the bridge. In this case however, the adjusting voltage is of such magnitude and relative polarity or phase angle with respect to V_1 that it aids or boosts V_1 , thereby increasing the primary or induced voltage E so as to compensate for the decrease in V_1 and maintain the output voltage V_2 substantially constant within its predetermined limits.

Up to this point it has been assumed that the voltage drops across the bridge reactors are cophasal in order to simplify the theoretical explanation of the control circuit 10. The cophasal relationship between the voltage drops across the bridge reactors is very nearly obtained when the current flowing in the primary 22 of the transformer 16 is small in comparison with the current flowing in the reactors of the bridge 32 due to the voltage across the corrector winding 30. However, these cophasal voltage conditions exist only rarely. When the transformer is loaded, the voltage drops across the different reactors of the bridge circuit are not cophasal due to load current flowing through the bridge reactors, and the voltage relations become much more complex. For example it has been found that under load conditions, when the bridge is balanced, i.e., when equal currents flow in the D.C. control winding of the bridge reactors, an undesirable voltage "e" appears across the corners 44 and 48 which is approximately at right angles to the voltage across corrector winding 30 and the voltage E across the primary winding 22. In such a case, the magnitude of the primary voltage E is close to its normal value and the magnitude of voltage V_2 is close to its normal value regardless of the fact that the voltage "e" appears across the corners 44 and 48 of the bridge. However, the primary voltage E, and therefore the voltage V_2 , is appreciably shifted in phase with respect to the supply voltage V_1 . It has also been found that this undesirable voltage "e" contains relatively high harmonics which are transformed into the output voltage V_2 and which may interfere with telephonic communications if the voltage control device 10 is used to transmit power along lines which are close to telephone lines.

On the other hand, when the bridge circuit 32 is unbalanced, as for example when the ratio of the impedance values of the reactance winding 40AC to the reactance winding 34AC and the ratio of the impedance values of the reactor winding 36AC to reactor winding 38AC are rather small, the voltage "e" across the corners 44 and 48 attains a nearly cophasal relationship with respect to the voltage across the corrector winding 30 or corners 42 and 46, and also with respect to the primary voltage E. Consequently, in such case the phase displacement between V_1 and V_2 is small. Also, the magnitudes of the harmonics in the compensating voltage under unbalanced bridge conditions are low.

Thus, when the input voltage V_1 and the output voltage V_2 are normal, the bridge circuit is in balance and a voltage "e" exists across bridge corners 44 and 48 which is substantially at right angles to the primary or induced voltage E, and which results in relatively high harmonics in the output voltage V_2 and an appreciable phase displacement between V_1 and V_2 . Consequently, when the output voltage is normal and a compensating voltage is not needed but does exist, it is advantageous to reduce the magnitude of this compensating voltage "e" to a minimum, and this is a function of the present invention.

In the illustrated embodiment of the present invention, the undesirable compensating voltage "e" which appears across terminals 44 and 48 of the bridge when the output voltage V_2 is normal, is greatly reduced so as to reduce the harmonics in the output voltage to a minimum and also to greatly reduce the phase shift between the supply voltage V_1 and output voltage V_2 . This is accomplished by connecting the variable impedance device 12, which is referred to as a harmonic and phase shift suppressor,

across terminals 44 and 48 of the bridge circuit 32 and automatically varying the impedance of the device in response to variations in the controlled output voltage V_2 in such a manner that when the output voltage V_2 is normal, the impedance of the device is at a minimum, and when the output voltage varies from normal, the impedance of the device is relatively high.

The phase shift and harmonic suppressor 12 shown in Fig. 1 comprises a saturable core reactor having a saturable magnetic core 92 on which is positioned a reactance winding 94 and a D.C. control winding 95. The reactance winding 94 has one end connected to the corner 44 and the other end connected to the corner 48 of the bridge circuit 32.

The suppressor control circuit 14 in Fig. 1 includes a self-saturating magnetic amplifier 96 which is somewhat similar to the amplifiers 60 and 62. The amplifier 96 is controlled in response to output voltage variations and its output is supplied to the control winding 95 of the suppressor reactor 12.

The amplifier 96 includes two saturable magnetic cores 98 and 99 containing reactance or power windings 100 and 102, respectively, control windings 104 and 105, respectively, control windings 106 and 107, respectively, and bias windings 108 and 109, respectively.

The power windings 100 and 102 are connected in a pair of parallel branch circuits 110 and 112, respectively, with the opposite ends of the branches having common junctions 114 and 115. A half-wave rectifier 116 is connected in branch 110 in series with the power winding 100, and a half-wave rectifier 117 is connected in branch 112 in series with power winding 102. The junction 114 is connected to terminal 118 of a pair of amplifier A.C. output terminals 118 and 118', while the junction 115 is connected to terminal 120 of a pair of amplifier A.C. power input terminals 120 and 120'. The power input terminal 120' and the power output terminal 118' are connected together.

The power input terminals 120 and 120' are connected to an A.C. power source indicated by the numeral 122, while the A.C. output terminals 118 and 118' of the amplifier are connected to a full-wave rectifier 124 whose D.C. output terminals are connected to the control winding 95 of the phase-shift and harmonic suppressor reactor 12. The power supply source 122 for the amplifier may be any suitable A.C. source, for example, the terminals 120 and 120' may be connected across the substantially constant output voltage circuit of the transformer 16.

The half-wave rectifiers 116 and 117 are oppositely poled or related with respect to the supply voltage applied to the power input circuit 120—120' so that the rectifiers conduct current on alternate half cycles of the supply voltage and provide an alternating current at output terminals 118 and 118'. Thus, intermittent pulsating unidirectional current flows in the power windings 100 and 102 and produces saturating M.M.F.'s which tend to saturate the cores and increase the output of the amplifiers. The direction of these saturating M.M.F.'s are indicated by the arrows adjacent the power windings 100 and 102.

The pair of control windings 104 and 105 of amplifier 96 are connected in series and connected by conductors 126 and 127 through an adjustable resistance 128 across the D.C. output terminals 83 and 84 of the rectifier 74 and are therefore energized in response to the output of amplifier 60. The pair of control windings 106 and 107 of the amplifier 96, in like manner, are connected in series and connected by conductors 129 and 130 through an adjustable resistance 131 across the D.C. output terminals 83' and 84' of the rectifier 74 and therefore are energized in response to the output of amplifier 62. Thus, in the circuit of Fig. 1, the outputs of amplifiers 60 and 62 control the relative impedances of the reactors in the bridge 32 and also determine the

output of amplifier 96, which in turn controls the impedance of the suppressor reactor 12.

The bias windings 108 and 109 are shown connected in series and to a bias current source indicated as a battery 133 and a series adjustable resistance 134. As indicated by the arrows adjacent these bias windings, the M.M.F.'s resulting from bias current flowing therethrough are in the saturating direction tending to raise the output of the amplifier. The magnitude of bias current for amplifier 96 is adjusted so that for a minimum total control current flowing in the control windings 104, 106, 107 and 105, the output of the amplifier 96 is at its maximum value.

The control windings 104, 105, 106 and 107 are so connected and wound that the M.M.F.'s resulting from current flow in these windings are in the desaturating direction as indicated by the arrows adjacent the windings, that is, these M.M.F.'s oppose saturation and tend to decrease the output of the amplifier 96. Thus, the output currents from both of the amplifiers 60 and 62 affect the amplifier 96 in the same sense so that their combined effect may be represented by the curve C in Fig. 3. With the output current of each of the amplifiers 60 and 62 at a relatively low value at the crossover point "p," the change in output current of one of the amplifiers will be greater than the change in output current of the other for a given change in the output current of the detector. Curve C represents the control ampere-turns of amplifier 96 and is obtained by adding the instantaneous values of the curves A and B.

Fig. 4 shows the control characteristic curve D of the amplifier 96.

Fig. 5 shows a curve Z which represents the impedance curve of the suppressor reactance winding 94 in relation to the control characteristic of the amplifier 96. It will be apparent that the output of the amplifier 96 (curve D) varies inversely with respect to the control ampere-turns of the amplifier (curve C), i.e., the output of amplifier 96 decreases as the ampere-turns increase, and vice versa. It will also be noted from the curves D and Z (Figs. 4 and 5) that the impedance of the reactance winding 94 varies inversely with respect to the output of the amplifier 96.

In operation, when the output voltage V_2 is normal, the detector 52 provides a control signal (indicated at a point "n" in Fig. 2) to the control windings of the amplifiers 60 and 62 which causes their respective outputs to be equal, as indicated at the cross-over point "p" in Fig. 3. This provides the two pairs of diametrically opposite control windings of the saturable reactor bridge circuit 32 with equal D.C. control currents whereby the bridge circuit is balanced. At the same time, the control windings 104, 105, 106 and 107 of amplifier 96 are energized by a control signal of minimum value, as indicated at point m on curve C, so that amplifier 96 has a maximum output (indicated by point d_1 on curve D, Fig. 4) to cause a relatively large current to flow through the control winding 95 of the suppressor reactor and reduce the impedance of the A.C. reactance winding 94 to a minimum value, as indicated by the point z_1 on curve Z in Fig. 5. Thus, when the output voltage V_2 is normal, the bridge is balanced and the otherwise present undesirable voltage "e," is made substantially ineffectual due to the fact that the suppressor reactor has a very low impedance and is connected across the bridge corners 44 and 48.

If the impedance of the suppressor reactance winding 94 could be reduced to zero when the output voltage is at its normal value, there would (in effect) be a short circuit across the diametrically opposite corners 44 and 48 of the bridge, and this would reduce the adjusting voltage "e" to zero, and there would be no high harmonics in the output voltage nor phase displacement whatsoever between the supply voltage and output voltage as a result of the control system. With the present inven-

tion this is closely approached. During an actual test, the value of the adjusting voltage "e," with the bridge balanced and the output voltage at the desired value, was reduced approximately 70%.

On the other hand, if the output voltage V_2 tends to vary above or below the normal value, the amplifier 96 automatically causes the impedance of reactance winding 94 to increase so that the compensating voltage "e" is effective in holding the output voltage V_2 within its predetermined limits.

Thus, for example, if the output voltage V_2 tends to increase above its normal value due to the supply voltage V_1 increasing to 110% of its normal value, the small increase in output voltage causes the output of the detector 52 to increase to a high value indicated at point "h" on the curve in Fig. 2, thereby increasing the output of amplifier 62 to a relatively high value (point b_2 , curve B) while decreasing the output of amplifier 60 to a low value, (point a_2 , curve A). This causes the saturable core reactor bridge 32 to become unbalanced and produce a correcting voltage "e" which opposes the impressed voltage V_1 so as to maintain the primary or induced voltage E substantially constant. At the same time, the resultant effective desaturating control M.M.F.'s due to signal currents from the amplifiers 60 and 62, which are applied to the control windings of amplifier 96, are increased to a high value, as indicated by point c_1 on curve C, and the output of amplifier 96 is decreased to a low value, as indicated at point d_2 on curve D, Fig. 4; consequently, the impedance of suppressor reactance winding 94 is high, as indicated by the point z_2 on curve Z in Fig. 5. Because the impedance of winding 94 is high, it has substantially no effect on the voltage "e" developed in the bridge. Therefore, the voltage "e" is effective and opposes the supply voltage V_1 , thereby tending to reduce the primary or induced voltage E and maintain the output voltage V_2 within its predetermined limits.

In like manner, if the output voltage V_2 tends to decrease from the normal value, for example due to the supply voltage decreasing to 90% of its normal value, the small decrease in output voltage causes the output current of detector 52 to decrease to a low value, such as indicated at point l on the curve in Fig. 2. The decrease in output current of the detector 52 causes the output of amplifier 60 to increase (point a_1 , curve A) and the output of amplifier 62 to decrease (point b_1 , curve B) thereby producing control signals which cause the bridge circuit 32 to become unbalanced. At the same time, the desaturating control M.M.F.'s due to signal currents from the amplifiers 60 and 62, which are applied to the control windings of the amplifier 96, are at a high value as indicated by a point c_2 on curve C. Consequently, the output of amplifier 96 is again reduced to a low value as indicated at point d_2 on curve D, Fig. 4, thereby causing the impedance of the suppressor reactor winding 94 to be high as indicated at point z_2 on curve Z. Because of the high impedance of the winding 94 under this unbalanced bridge condition, the voltage "e" developed in the bridge 32 is again effective; however, in this case it is aiding the supply voltage V_1 and tending to raise the primary or induced voltage E and to thereby maintain the output voltage V_2 within its predetermined limits.

Fig. 6 graphically illustrates the operation of the system of Fig. 1 and the effect of the suppressor 12 and control circuit 14 in greatly reducing and maintaining the phase shift between V_1 and V_2 at a minimum. In Fig. 6 it is assumed that the output voltage V_2 tends to vary due to variations in the supply voltage V_1 . The vector $o-a$ represents the supply voltage at its normal value, the vector $o-b$ represents the supply voltage when above normal, and the vector $o-c$ represents the supply voltage when below normal. The dashed-line curve "r" represents the locus of the ends of the compensating voltage

vectors which would result if the automatic suppressor were not employed. The curve "s" represents the locus of the ends of the compensating voltage vectors when the automatic suppressor is employed.

When V_1 is above normal as indicated by vector $o-b$, the bridge 32 is unbalanced in the manner described above and the compensating voltage "e," appearing across bridge terminals 44 and 48, is indicated by vector $o-b'$. Combining these vectors results in the vector E which represents the desired or normal primary or induced voltage necessary to obtain normal output voltage. When V_1 is below normal as indicated by vector $o-c$, the bridge is unbalanced in the opposite sense and the compensating voltage "e" is indicated by the vector $o-c'$. Combining vectors $o-c$ and $o-c'$ results again in the vector E. Thus, if the supply voltage varies above or below its normal value, the compensating voltage "e" correspondingly affects the primary voltage in a manner to maintain the output voltage at substantially its normal value.

The vector $o-a''$ represents the voltage which would appear across the bridge terminals 44 and 48 when the supply and output voltages are substantially normal and the bridge is balanced, if the automatic suppressor were not employed. The vector $o-a''$ is substantially at right angles to V_1 and is of such magnitude that when combined with the normal supply voltage vector $o-a$, the primary voltage vector E_n is obtained. It is apparent that the phase shift between E_n and V_1 is rather large and this would mean that the phase shift V_1 and V_2 would also be rather large.

The vector $o-a'$ represents the reduced voltage which appears across the bridge terminals 44 and 48 when the output voltage V_2 is normal and the automatic suppressor of the present invention is employed.

Combining the normal supply voltage vector $o-a$ and the vector $o-a'$ results in the desired primary voltage vector E. Thus it is apparent that when the output voltage V_2 is at the desired value, the phase shift between the supply and output voltages is reduced and maintained substantially constant.

It was also found that the V.A.R.'s (volt-ampere-reactive) required by the control system using the controlled suppressor reactor (for most load conditions) was less than that required when the suppressor reactor was not used.

Fig. 7 shows a partial schematic diagram illustrating a modified form of the present invention, where, as in the circuit of Fig. 1, the suppressor reactor 12 is controlled in response to variations in the output voltage V_2 . However, in the circuit shown in Fig. 7, the suppressor control amplifier 96a has only one pair of control windings 136 and 138 and these control windings are supplied by the direct current output of a full-wave rectifier 140. The rectifier 140 has its alternating current input terminals connected to be supplied by a voltage proportional to the difference between the A.C. output voltages of the amplifiers 60 and 62.

Thus, rectifier 140 has one of its A.C. input terminals connected to the A.C. output terminal 73 of the amplifier 60 by a conductor 142, while the other input terminal of the rectifier is connected to the A.C. output terminal 73' of the amplifier 62 through a conductor 144. Therefore, as in the circuit of Fig. 1, the outputs of the amplifiers 60 and 62 control the impedance of the reactor 12.

The amplifier 96a, like amplifier 96 of Fig. 1, is shown with bias windings 108' and 109' and a bias current source 133', 134'. The bias current flows in the saturating direction through the bias windings 108' and 109' and the magnitude of bias current is adjusted so that a high current flows in the output circuit of the amplifier 96a when a low or zero signal current flows in the control windings 136 and 138.

The signal voltage applied to the input terminals of

the rectifier 140 will vary from zero to a relatively high value in accordance with the difference between the A.C. outputs of the amplifiers 60 and 62.

When the output voltage V_2 is at its normal value, the amplifiers 60 and 62 have substantially equal output currents and operate to balance the bridge 32. Therefore, the potential between terminals 73 and 78 is substantially equal to the potential between terminals 73' and 78 since both amplifiers are supplying substantially equal currents to substantially equal loads; the loads here being the D.C. control circuits of the bridge 32. Thus, the voltage across the terminals 73 and 73', and therefore across the A.C. input terminals of the full-wave rectifier 140, is substantially zero. It will be evident therefore, that when the output voltage V_2 is normal and the bridge is balanced, the control windings 136 and 138 have little or no current flowing through them and the output of amplifier 96a is at its maximum value, thereby causing the impedance of the suppressor reactance winding 94 to be at its minimum value as desired.

If the output voltage V_2 drops to a value below normal, as for example due to the supply voltage decreasing to 90% of its normal value, the output of amplifier 60 increases while the output of amplifier 62 decreases. Because the change in output current of amplifier 60 (curve A, Fig. 3) is greater than the change in the output current of amplifier 62 (curve B, Fig. 3) the terminals 73 and 73' will be at different potentials and an A.C. voltage will exist across the conductors 142 and 144. Control current due to this A.C. voltage is rectified by the full-wave rectifier 140 to energize the control windings 136 and 138 thereby producing desaturating control M.M.F.'s to lower the output of amplifier 96a and cause the impedance of the A.C. reactance winding 94 to be increased.

If the output voltage V_2 increases to a value above normal, as for example due to the supply voltage increasing to 110% of its normal value, the output of amplifier 62 increases while the output of amplifier 60 decreases. Because the change in the output of amplifier 62 is greater than the change in the output of amplifier 60 (curves A and B, Fig. 3), the potentials of the terminals 73 and 73' are different, and an A.C. voltage exists across the conductors 142 and 144, thereby producing desaturating M.M.F.'s and reducing the output of amplifier 96a and causing the impedance of the reactance winding 94 to be high.

Thus, the suppressor reactor 12 in Fig. 7 is also automatically controlled in response to variations in the output voltage V_2 in such manner that the suppressor reactance winding 94 presents a minimum impedance across the bridge terminals 44 and 48 when the output voltage is normal, and a relatively high impedance across these bridge terminals when the output voltage tends to vary from the normal value.

The voltage impressed across bridge corners 42 and 46 in Fig. 1 is obtained by means of the corrector winding 30 on the transformer 16, however, this voltage may be obtained by means of a separate transformer. For example, where it is desired to connect a power supply source directly to a load circuit without the use of a power transformer, such as transformer 16, the voltage impressed across these bridge corners may be obtained from a separate transformer connected across the load circuit.

While the bridge circuit 32 in Fig. 1 is shown connected in power line 23 in series with the primary winding of power transformer 16, it may be connected in the secondary winding side of the transformer if desired. Also, although the bridge circuit is shown conductively coupled into the power line, it may be coupled into a power line by means of an additional transformer. In such a case, instead of connecting the bridge corners 44 and 48 directly into the power line as shown, the primary winding of the additional transformer is connected across

these bridge corners with the secondary winding connected in series in the power line.

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. In a voltage control system comprising a Wheatstone type bridge circuit including two sets of opposed impedances and two sets of opposed corners, means for impressing a voltage across one set of corners, and means for varying the magnitude of at least one set of impedances responsive to a selected electrical condition in the system for producing a variable voltage across the other set of corners; the improvement which comprises a variable impedance connected between said other set of corners; circuit means for producing a signal responsive to said electrical condition; and means responsive to said signal for varying the magnitude of said impedance responsive to said selected electrical condition in the system.

2. In a voltage control system comprising a Wheatstone type bridge circuit containing two sets of opposed impedances and two sets of opposed corners, means for impressing a voltage across one set of corners, and means for varying the magnitude of at least one set of impedances for producing a variable voltage across the other set of corners, said means being responsive to a selected electrical condition in the system which varies from a normal value to values above and below normal: the improvement which comprises a variable impedance connected between said other set of corners; circuit means for deriving a signal responsive to the variations in said electrical condition; and means responsive to said signal for varying the magnitude of said impedance responsive to said selected electrical condition in the system so that the magnitude of the impedance is at a minimum when said electrical condition is at its normal value.

3. In a voltage control system containing power input and output circuits; means for producing a correcting voltage, including a Wheatstone type bridge circuit containing two sets of opposed impedances and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit between the power input and output circuits; and means for varying the magnitude of both sets of impedances responsive to a selected electrical condition in the system, including a first and a second source of current: the improvement which comprises a variable impedance connected between said other set of corners; and means for varying the magnitude of said impedance responsive to the sum of the currents flowing from said first and second sources.

4. In a voltage control system containing power input and output circuits; means for producing a correcting voltage, including a Wheatstone type bridge circuit containing two sets of opposed impedances and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit between the power input and output circuits; and means for varying the magnitude of both sets of impedances responsive to a selected electrical condition in the system, including a first and a second source of electrical potential: the improvement which comprises a variable impedance connected between said other set of corners; and means for varying the magnitude of said impedance responsive to the difference between said first and second sources of electrical potential.

5. In combination in a voltage control system, power input and output circuits; means for producing a correcting voltage, including a Wheatstone type bridge cir-

cuit containing two sets of saturable core reactors and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit in series between the power input and output circuits; means for varying the impedances of the saturable core reactors responsive to a selected electrical condition in the system, including a first source of D.C. current connected to one set of reactors and a second source of D.C. current connected to the other set of reactors; a variable impedance connected between said other set of corners; and means for varying the magnitude of said impedance responsive to the sum of the D.C. currents flowing from said first and second sources of D.C. current.

6. In an electrical control system containing power input and output circuits; means for producing a correcting voltage, including a Wheatstone type bridge circuit having two sets of opposed impedances and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit between the power input and output circuits; and means for varying the magnitude of at least one set of impedances: the improvement which comprises a saturable core reactor connected in circuit between said other set of corners, means for producing a current directly proportional to said electrical condition above a predetermined magnitude, means for producing a current inversely proportional to said electrical condition above said predetermined magnitude, and means responsive to said currents for reducing the impedance of said reactor to a minimum only when said currents are substantially equal.

7. In an electrical control system having means for producing a variable voltage across a pair of circuit terminals, said means including two sets of saturable core reactors, means responsive to an electrical condition in the system for varying the impedance of at least one set of reactors when the magnitude of said electrical condition varies from a predetermined value; the improvement which comprises an additional saturable core reactor connected in circuit across said circuit terminals, means for varying the impedance of said additional reactor and other means connected to said impedance varying means and responsive to said electrical condition, said other means changing the current flow through the impedance varying means to reduce the impedance of said last named reactor to a minimum only when the magnitude of said electrical condition is at said predetermined value.

8. In combination in a voltage control system, a power input circuit connectable to a supply voltage source; a power output circuit connectable to a load; means for producing a correcting voltage, including a Wheatstone type bridge circuit containing two sets of saturable core reactors and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit in series between the power input and output circuits; means for varying the impedances of the saturable core reactors responsive to a selected electrical condition in the system, including a first source of D.C. current connected to one set of reactors and a second source of D.C. current connected to the other set of reactors; a variable impedance connected between said other set of corners; and means for varying the magnitude of said impedance responsive to the sum of the D.C. currents flowing from said first and second sources of D.C. current, including a magnetic amplifier containing two control windings, one of said control windings being connected to the first source of D.C. current, and the other of said control windings being connected to the second source of D.C. current.

9. In combination in a voltage control circuit, a power input circuit connectable to a supply voltage source; a power output circuit connectable to a load; means for producing a correcting voltage, including a Wheatstone

type bridge circuit containing two sets of saturable core reactors and two sets of opposed corners, and means for impressing a voltage across one set of corners, the other set of corners being connected in a circuit in series between the power input and output circuits; means for varying the impedances of the saturable core reactors responsive to a selected electrical condition in the system, including a first source of D.C. current connected to one set of reactors and a second source of D.C. current connected to the other set of reactors; a saturable core reactor connected between said other set of corners; a self-saturating magnetic amplifier containing a power winding and two control windings, the control windings being wound so as to oppose the M.M.F. of the power winding; connections between the first source of D.C. current and one of said control windings; connections between the second source of D.C. current and the other of said control windings; and means connecting the output of the amplifier with the saturable core reactor connected between said other set of corners so that the impedance of said last named reactor varies inversely with the output of the amplifier.

10. In combination in a voltage regulating circuit, a transformer containing a main primary winding and a main secondary winding; means connected with one of said windings for producing a correcting voltage, including a Wheatstone type bridge circuit containing two sets of saturable core reactors and two sets of opposed corners, and transformer means for impressing a voltage across one set of corners, the other set of corners being connected in the circuit containing said one of said main windings; means for varying the impedances of the saturable core reactors responsive to a selected electrical condition in the circuit, including a first source of D.C. current connected to one set of reactors and a second source of D.C. current connected to the other set of reactors; a saturable core reactor connected between said other set of corners; a self-saturating magnetic amplifier containing a power winding, two control windings, and a bias winding; the control windings being wound so as to oppose the M.M.F. of the power winding, and the bias winding being wound to aid the M.M.F. of the power winding; a source of bias current connected to the bias winding; means for varying the current through the bias winding; connections between the first source of D.C. current and one of said control windings; connections between the second source of D.C. current and the other of said control windings; and means connecting the output of the amplifier with the saturable core reactor connected between said other set of corners so that the impedance of said last named reactor varies inversely with the output of the amplifier.

11. In combination in a voltage regulating circuit, a transformer containing a main primary winding and a main secondary winding; means connected with one of said main windings for producing a correcting voltage, including a Wheatstone type bridge circuit containing two sets of saturable core reactors and two sets of opposed corners, and a corrector winding connected to supply a voltage across one set of corners, the other set of corners being connected in the circuit containing said one of said main windings; means for varying the impedances of the saturable core reactors responsive to a selected electrical condition in the circuit, including a first source of D.C. current connected to one set of reactors and a second source of D.C. current connected to the other set of reactors, whereby there is a potential drop across each set of reactors; a variable impedance connected between said other set of corners; and means for varying the magnitude of said variable impedance responsive to the difference in the potentials across the two sets of reactors, including a self-saturating magnetic amplifier containing two power windings, and a control winding wound to oppose the M.M.F. of the power windings, the control winding being connected to the D.C. current sources

so that the current which flows through said control winding is proportional to said difference in potential across the two sets of reactors.

12. In combination, two sets of opposed saturable core reactors, each set including two A.C. reactance windings and at least one D.C. control winding, the A.C. reactance windings of the sets being connected together to form a Wheatstone type bridge circuit having two sets of diametrically opposite bridge corners, means for impressing an A.C. voltage across one set of bridge corners, means for controlling the balance conditions of said bridge circuit including said D.C. control windings, a saturable core reactor including a reactance winding connected in circuit across the other set of bridge corners, means for varying the impedance of said last named reactor, and other means connected to the impedance varying means and responsive to the balance conditions of said bridge circuit for changing the current flow through said impedance varying means so as to reduce the impedance of said latter reactance winding to a minimum only when said bridge circuit is in balance.

13. In an electrical control system containing means for producing a variable voltage, said means comprising at least four impedances connected together to form a Wheatstone type bridge circuit having two sets of opposed bridge corners, means for impressing a voltage across one set of bridge corners, and means for varying the value of at least one of said impedances for producing said variable voltage across the other set of bridge corners; the combination with the voltage producing means of a shunt circuit connected across said other set of bridge corners, a variable impedance device connected in said shunt circuit, means for varying the impedance of said device, and other means connected to said impedance varying means responsive to the magnitude of an electrical condition of the system changing the current flow through the impedance varying means so as to reduce the impedance of said impedance device to a minimum when the magnitude of said electrical condition is at a predetermined value, and for increasing the impedance of said device when said electrical condition varies from said predetermined value.

14. In an electrical control system containing means for producing a variable voltage, said means comprising at least four impedances connected together to form a Wheatstone type bridge circuit having two sets of opposed bridge corners, means for impressing a voltage across one set of bridge corners, and means for varying the value of at least one of said impedances for producing said variable voltage across the other set of bridge corners; the combination with the voltage producing means of a shunt circuit connected across said other set of bridge corners and including a saturable reactor containing a magnetic core, an A.C. reactance winding on said core, and a D.C. control winding on said core for controlling the impedance of said reactance winding, an amplifier having an output circuit connected to supply output current to said control winding, and a signal input circuit for controlling the magnitude of said output current, and means for energizing said signal input circuit in response to the magnitude of an electrical condition of the system to increase the magnitude of said output current to a maximum when said electrical condition is at a predetermined magnitude and to decrease said output current when said electrical condition varies from said predetermined magnitude.

15. In an electrical control system containing means for producing a variable voltage, said means comprising at least four impedances connected together to form a Wheatstone type bridge circuit having two sets of opposed bridge corners, means for impressing a voltage across one set of bridge corners, and means for varying the value of at least one of said impedances for producing said variable voltage across the other set of bridge corners; the combination with the voltage pro-

ducing means of a shunt circuit connected across said other set of bridge corners and including a saturable reactor containing a magnetic core, a reactance winding on said core, and a control winding on said core for controlling the impedance of said reactance winding, means for producing a first signal directly proportional to an electrical condition of the system above a predetermined magnitude, means for producing a second signal inversely proportional to said electrical condition above said predetermined magnitude, means for combining said first and second signals to produce a third signal, and means responsive to said third signal for energizing said control winding.

16. An electric control system comprising a power input circuit connectable to a supply voltage source, a power output circuit connectable to a load, means including a pair of conductors for connecting the power input circuit with the power output circuit, a bridge circuit including four impedances connected together to form two sets of opposed impedances and two sets to diametrically opposite bridge corners, means for impressing a voltage across one set of corners, means for varying at least one of said impedances to provide a variable voltage across the other set of corners, means coupling said variable voltage in series with said supply voltage, a shunt circuit connected across said other set of corners, a saturable reactor including a magnetic core, a reactance winding on said core and connected in said shunt circuit, and a control winding on said core, first and second amplifiers, means for controlling the output of each of said amplifiers in response to an electrical condition of the system, said first amplifier producing an output which decreases when said electrical condition increases above a predetermined magnitude, said second amplifier producing an output which increases when said electrical condition increases above said predetermined magnitude, a third amplifier having an output circuit connected to supply output current to said reactor control winding, and means for controlling the output current of said third amplifier in response to the outputs of said first and second amplifiers.

17. An electrical control system comprising a system power input circuit connectable to a supply source, a system power output circuit connectable to a load, a bridge circuit including four saturable core reactors connected together to form two sets of diametrically opposite reactors and two sets of diametrically opposite bridge corners, each set of reactors having at least one D.C. control winding, means for impressing a voltage across one set of bridge corners, means including the other set of corners for connecting said bridge circuit in series between the power input and output circuits, a shunt circuit connected across said other set of bridge corners, a saturable reactor including a magnetic core, a reactance winding on said core and connected in said shunt circuit, and a reactor control winding on said core, a pair of self-saturating magnetic amplifiers, each of said amplifiers comprising power input and output circuits, a saturable core, a power winding on said core and connected between the power input and output circuits, and a control winding on said core, means for producing a signal responsive to an electrical condition of the system, means for supplying said signal to the control winding of each of said amplifiers for inversely affecting the outputs of said amplifiers, means for energizing one D.C. control winding in response to the output of one of said amplifiers, means for energizing the other D.C. control winding in response to the output of the other of said amplifiers, a third amplifier comprising power input and output circuits, a saturable core, a power winding on said core and connected between the power input and output circuits, and a signal input circuit including a control winding on said core, means for energizing said signal input circuit of said third amplifier in response to the outputs of said pair of amplifiers, and means for ener-

gizing said reactor control winding of the reactor of said shunt circuit in response to the output of said third amplifier.

18. An electric control system comprising a system power input circuit connectable to a supply source, a system power output circuit connectable to a load, a bridge circuit including four saturable core reactors connected together to form two sets of diametrically opposite reactors and two sets of diametrically opposite bridge corners, each set of reactors having at least one D.C. control winding, means for impressing a voltage across one set of bridge corners, means including the other set of corners for connecting said bridge circuit in series between said power input and output circuits, a shunt circuit connected across said other set of bridge corners, a saturable reactor including a magnetic core, a reactance winding on said core and connected in said shunt circuit, and a reactor control winding on said core, a pair of self-saturating magnetic amplifiers, each of said amplifiers comprising power input and output circuits, a saturable core, a power winding on said core and connected between the power input and output circuits, a rectifier in series with the power winding for producing self-saturating M.M.F.'s when a voltage is applied to the power input circuit, and a control winding on said core, means for producing a signal responsive to the voltage across said system output circuit, means for energizing the control winding of one of said amplifiers in response to said signal to produce desaturating M.M.F.'s, means for energizing the control winding of the other amplifier in response to said signal to produce saturating M.M.F.'s, means for energizing one D.C. control winding in response to the output of one of said amplifiers, means for energizing the other D.C. control winding in response to the output of the other of said amplifiers, a third amplifier comprising power input and output circuits, a saturable core, a power winding on said core and connected between the power input and output circuits of the third amplifier, a rectifier in series with the power winding for providing self-saturating M.M.F.'s when a voltage is applied to the power input circuit of the third amplifier, and a signal input circuit including at least two control windings on said core, means for energizing one of said latter control windings in response to the output of one of the amplifiers of said pair, means for energizing the other of said latter control windings in response to the output of the other amplifier of said pair, and means for energizing said reactor control winding of the reactor in said shunt circuit in response to the output of said third amplifier.

19. In an electrical control system having an A.C. source, means for producing a variable phase voltage across circuit points in the system, including means for varying the phase of said voltage with respect to the voltage of said source in response to an electrical condition in the system which varies from a normal value to values above and below normal, the improvement which comprises impedance means connected between said circuit points, circuit means for deriving a signal responsive to said electrical condition, and means including impedance control means responsive to said signal for reducing the value of said impedance means to a minimum when the electrical condition is at its normal value and increasing the value of said impedance means when the electrical condition varies above or below the normal value.

20. The combination of a bridge circuit having bridge input and output circuits, means for supplying a voltage to the bridge input circuit, bridge control means for controlling the balance of the bridge circuit to provide a variable voltage at the bridge output circuit; and a variable impedance device connected in a circuit across the bridge output circuit, said variable impedance device comprising a variable impedance member, means for varying the impedance of said member, circuit means connected to said impedance varying means for produc-

ing a signal responsive to the balance conditions of the bridge circuit, said circuit means including means responsive to said signal for changing the current flow through the impedance varying means so as to vary the impedance of the impedance member in such a way that the impedance is at a relatively low value when the bridge is balanced and at a higher value when the bridge is unbalanced.

21. The combination of a bridge circuit having bridge input and output circuits, means for supplying a voltage to the bridge input circuit, bridge control means for controlling the balance of the bridge circuit to provide a variable voltage at the bridge output circuit, a variable impedance device connected in a circuit in parallel with the bridge output circuit, and means for varying the impedance of said device so that it is at a minimum when the bridge is substantially balanced and at a higher value when the bridge is unbalanced, said latter means comprising an amplifier having an output circuit and a signal input circuit for controlling the output of the amplifier, circuit means for energizing said signal input circuit in response to the balance conditions of the bridge circuit, and means for varying the impedance of said device in response to the output of said amplifier.

22. In an electrical control system including a transformer having a main winding for supplying power to a power output circuit, a bridge circuit having bridge input and output circuits, means for supplying a voltage to the bridge input circuit, bridge control means for controlling the balance of the bridge circuit in response to an electrical condition of the system which is variable from a normal value to values above and below the normal value, means coupling the bridge output circuit in series with said main winding, a variable impedance device connected in a circuit across the bridge output circuit, circuit means responsive to said electrical condition for producing a signal which varies from a minimum value when said electrical condition is at said normal value to a higher value when said electrical condition varies above or below said normal value, an amplifier having an output circuit and a signal input circuit adapted to control the output of said amplifier, means for energizing said signal input circuit in response to said signal, and means for varying the impedance of said device in response to the output of said amplifier.

23. In an electrical power system including power leads for transmitting A.C. power from an A.C. power source to an A.C. power output circuit, the combination of a bridge circuit having bridge input and output circuits and including at least two saturable reactors each

having an A.C. reactance winding connected in a different arm of the bridge circuit, each of said reactors having a D.C. control winding, means coupling said bridge output circuit in series in one of said power leads, means for supplying an A.C. voltage to said bridge input circuit, control means including means for supplying D.C. current to the D.C. control windings of said reactors to control the balance of the bridge circuit for providing an adjusting voltage at the bridge output circuit, an additional saturable reactor having an A.C. reactance winding and a D.C. control winding, said latter A.C. reactance winding being connected in a circuit in parallel with said bridge output circuit, circuit means including a magnetic amplifier for deriving a signal responsive to the balance condition of the bridge circuit, and means for energizing the D.C. control winding of said additional reactor in response to said signal.

24. In an electrical control system, the combination of a bridge circuit having bridge input and output circuits and including at least two saturable reactors each having a reactance winding connected in a different arm of the bridge circuit, each of said reactors having a control winding, a pair of amplifiers each having an output circuit and a signal input circuit for controlling the output of the amplifier, detector means for deriving a signal responsive to an electrical condition in the system, means for energizing the signal input circuits of said amplifiers in response to said signal for varying the outputs of said amplifiers inversely with respect to each other, means for supplying current variable in accordance with the output of one of said amplifiers to the control winding of one of said reactors, means for supplying current variable in accordance with the output of the other of said amplifiers to the control winding of the other of said reactors, an additional saturable reactor having a reactance winding and a control winding, said latter reactance winding being connected in a circuit in parallel with said bridge output circuit, a third amplifier having an output circuit and a signal input circuit for controlling the output of said third amplifier, means for energizing said signal input circuit of the third amplifier in response to the outputs of said pair of amplifiers, and means for energizing the control winding of said additional reactor in response to the output of said third amplifier.

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