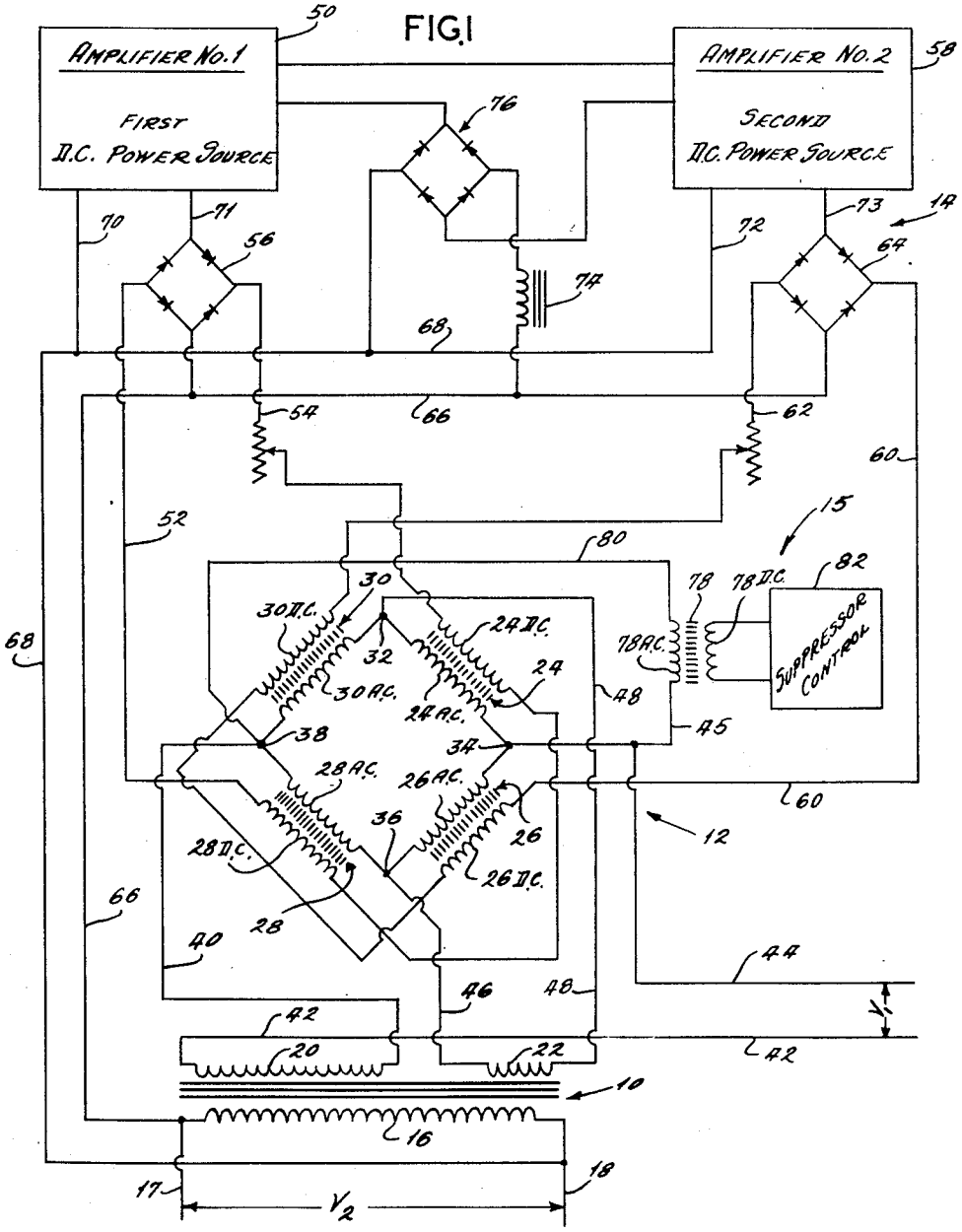
April 5, 1960 E. B. HILKER 2,931,970

HARMONIC SUPPRESSOR FOR VOLTAGE CONTROL DEVICE

Filed Aug. 26, 1957 3 Sheets-Sheet 1

FIG. 1



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HARMONIC SUPPRESSOR FOR VOLTAGE CONTROL DEVICE

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FIG. 2

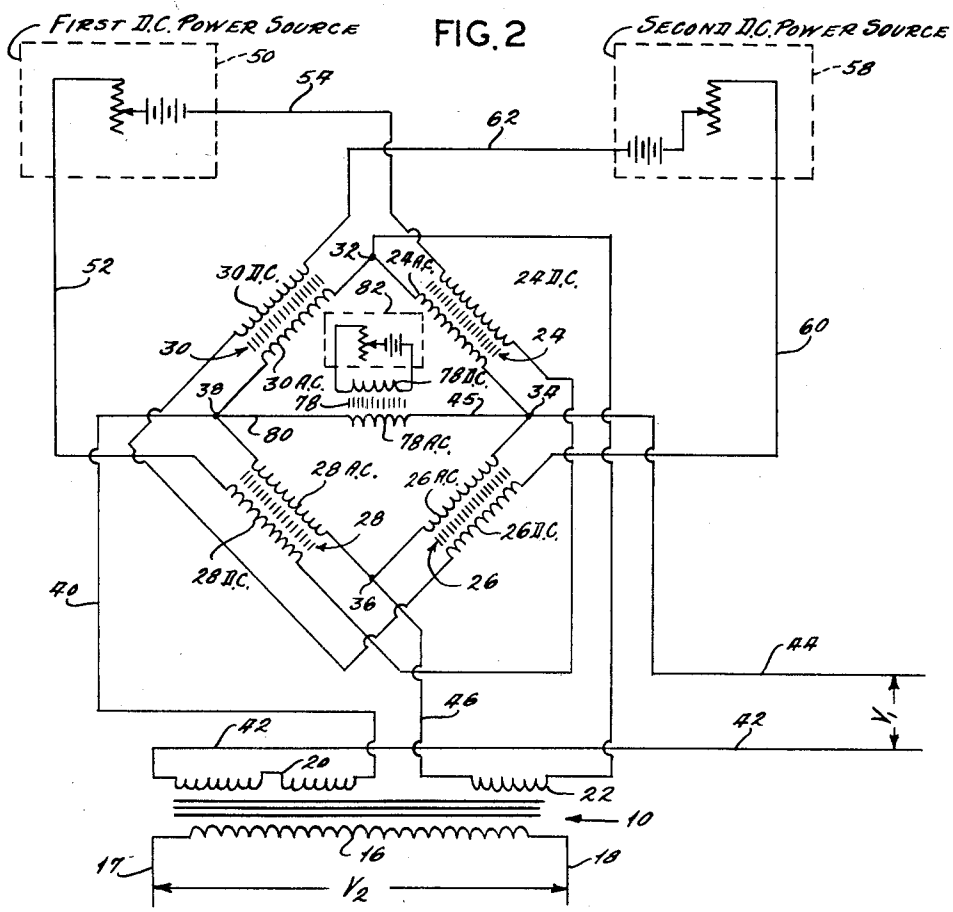
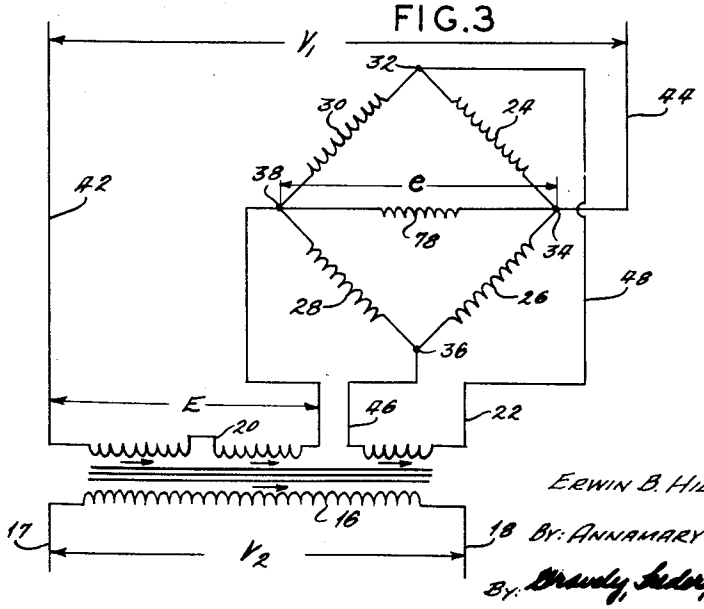


FIG. 3



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HARMONIC SUPPRESSOR FOR VOLTAGE CONTROL DEVICE

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FIG. 4

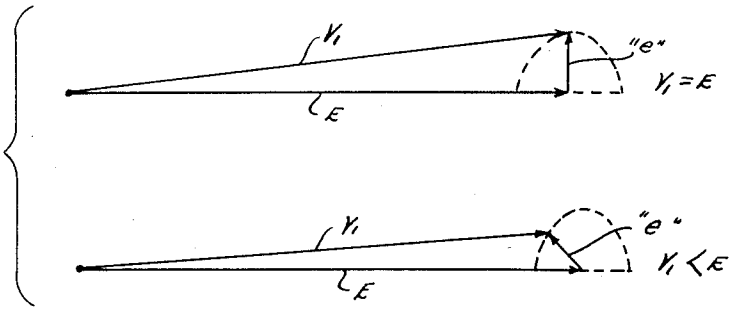


FIG. 5

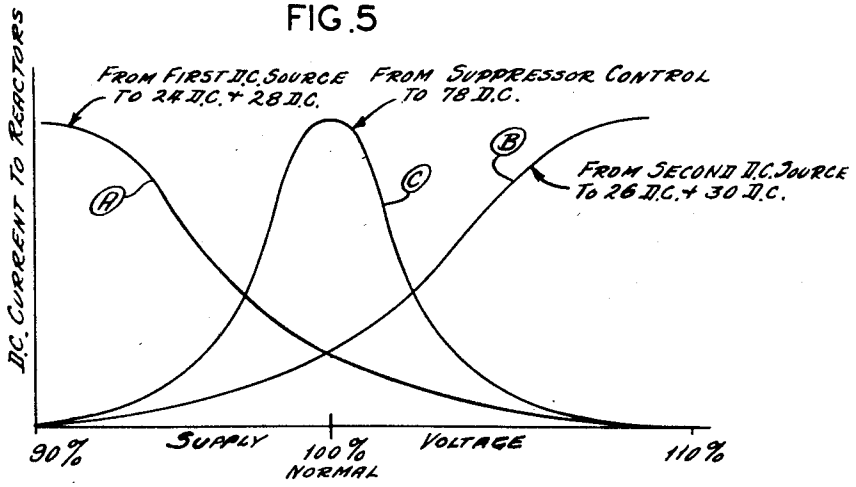
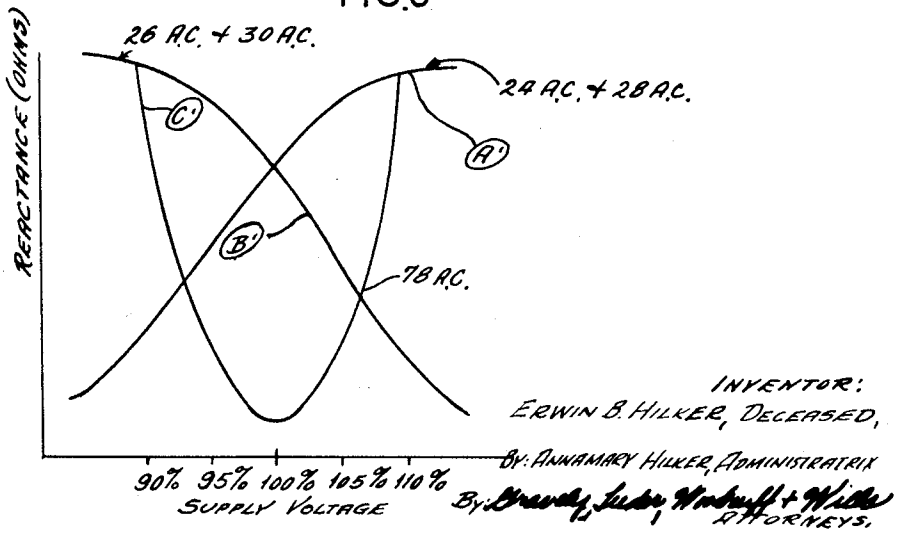


FIG. 6



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2,931,970

HARMONIC SUPPRESSOR FOR VOLTAGE CONTROL DEVICE

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Application August 26, 1957, Serial No. 680,342

12 Claims. (Cl. 323—75)

The present invention relates generally to the voltage control art, and more particularly to a novel harmonic and phase shift suppressor 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.

The inventions described in the aforementioned applications include means in combination with a transformer for providing a variable compensating or adjusting voltage which is superposed on, or "injected" into either the input or the output voltage of the transformer so as to maintain the output voltage at substantially the desired value, regardless of changes in the supply voltage within predetermined limits. In the preferred construction, the adjusting voltage is developed in a bridge circuit of four saturable core reactors whose impedances are responsive to selected external conditions, the magnitude and direction of the adjusting voltage being determined by the relative impedance value of the arms of the bridge circuit; for example, the impedances of the reactors forming the bridge circuit may be controlled automatically responsive to the magnitude of the supply voltage. Furthermore, the control of the transformer may be so set as to hold a constant voltage at the load terminals at the transformer station, or at a selected remote location, regardless of the changes of the supply voltage within predetermined limits.

Although the control device referred to hereinabove has operated very satisfactorily, it has been found that under certain load conditions the voltage across the load contains higher harmonics which may interfere with telephonic communication, and, in addition, the phase angle between the supply and output voltages is somewhat greater than desired.

Therefore, it is an object of the present invention, to provide a novel suppressor for use with the aforementioned voltage control device, for maintaining the output voltage substantially free of harmonic components.

Another object is to provide such a suppressor which will maintain the phase shift between the supply voltage and the output voltage small and substantially constant.

A further object is to provide a suppressor which will reduce the maxima or "peaks" of the voltage waves across the individual reactors of the bridge circuit and which result from the harmonic voltages contained in these voltages.

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

Briefly, the invention comprises an electro-magnetic impedance connected in parallel with the adjusting voltage within the bridge circuit and which is reduced to a relatively small value when the supply voltage is substantially normal, and which is maintained at a relatively high value when the supply voltage is abnormal.

In the drawings:

Fig. 1 is a schematic wiring diagram illustrating the circuit of a voltage control device and a harmonic suppressor constructed in accordance with the teachings of the present invention,

Fig. 2 is a simplified wiring diagram of the same circuit as shown in Fig. 1 in which the automatic control components of the impedances of the saturable reactors forming the Wheatstone bridge have been removed.

Fig. 3 is a further simplified schematic wiring diagram in which only the minimum A.C. circuit is shown and the control means for adjusting the impedance of the suppressor reactor as well as the impedances of the Wheatstone bridge saturable reactors are omitted.

Fig. 4 comprises two vector diagrams showing the supply voltage and the primary voltage when the supply voltage is normal, and when it is greater than the primary voltage,

Fig. 5 comprises a set of curves showing the magnitude of the D.C. currents to the saturable core reactors of the Wheatstone bridge and to the saturable core reactor of the suppressor, for different values of supply voltage, and

Fig. 6 comprises a set of curves showing the reactance values of the various saturable core reactors for different values of supply voltage.

Referring to the drawings more particularly by reference numerals, **10** indicates a power transformer, the output of which is to be controlled. The adjusting voltage which is superposed on the voltage of the transformer **10** is developed in a bridge circuit **12** and the magnitude and direction of the adjusting voltage is determined by a control circuit **14**. These components of the circuit are disclosed in the aforementioned copending applications.

The numeral **15** indicates generally a suppressor circuit and control which is the subject matter of the present invention, as used in combination with the aforementioned bridge circuit.

The transformer **10** includes a secondary winding **16** which is connected to a load by leads **17** and **18**, a primary winding **20** and a correcting winding **22**.

The Wheatstone bridge circuit **12** includes four saturable core reactors **24**, **26**, **28** and **30**, each of which comprises an A.C. winding and a D.C. winding which are identified by like numbers with the letters D.C. or A.C. added thereto. The A.C. windings of the saturable core reactors are connected together at corners **32**, **34**, **36** and **38**.

One end of the primary winding **20** of the transformer is connected to the corner **38** of the bridge by a conductor **40**, and the other end thereof is connected to a supply lead **42**. One end of the correcting winding **22** is connected to the corner **36** by a conductor **46**, and the other end thereof is connected to the opposite corner **32** by a conductor **48**. The remaining corner **34** is connected to the other supply lead **44** by a conductor **45**.

Turning next to a consideration of the D.C. windings of the reactors, the windings **24DC** and **28DC** are connected in series circuit and are connected to a first amplifier **50** through conductors **52** and **54** and a rectifier circuit **56**. This portion of the circuit will be referred to hereinafter as the first D.C. power source.

In like manner, the windings **26DC** and **30DC** are connected in series circuit and are connected to a second amplifier **58** through conductors **60** and **62** and a rectifier circuit **64**. This part of the circuit will be referred to hereinafter as the second D.C. power source.

Both the first and second D.C. power sources are energized from the load side of the transformer **10** through conductors **66** and **68** which are connected to the load leads **17** and **18**, respectively. The output of each of said two D.C. power sources is also responsive to the

voltage across conductors 66 and 68 (i.e. the load voltage) as by means of the current flowing through conductors 70, 71, 72 and 73, and through a voltage detector 74 and a rectifier circuit 76 which passes a proportionately larger current for each change in voltage after the voltage across the conductors 66 and 68 exceeds a predetermined amount. The construction and operation of this circuit are described in detail in the aforementioned copending application Serial No. 497,978.

Turning next to the suppressor circuit and control 15 with which we are particularly concerned (Fig. 1), this part of the circuit includes a saturable core reactor 78 which contains an A.C. winding 78AC and a D.C. winding 78DC. One end of the winding 78AC is connected to the corner 34 of the bridge by the conductor 45, and the other end thereof is connected to the opposite corner 38 of the bridge by means of a conductor 80. The winding 78DC in turn is connected to a suppressor control 82 (shown diagrammatically). For ease of description of the operation, the suppressor control 82 is shown (Fig. 2) as comprising a manually operable variable resistor and a battery. Manifestly, the battery can be replaced by a rectifier circuit receiving its A.C. input energy from the constant A.C. voltage appearing across the leads 17 and 18 of the output winding of the transformer 10, and the control can be made automatically responsive to selected external conditions. The various types of automatic control circuits which may be used with the harmonic suppressor 15 is the subject matter of copending application Serial No. 687,084, filed September 30, 1957.

The D.C. excitation of the suppressor reactor is set to a relatively high value when the supply A.C. voltage is normal in order to decrease the impedance of the A.C. winding of the suppressor reactor. On the other hand, the D.C. excitation of the suppressor reactor is set to a very low value when the supply voltage is abnormal in order to increase the impedance of the A.C. winding of the suppressor reactor to a very high value.

The normal supply voltage condition is a specific point in the operational curve C (Fig. 5), where the suppressor circuit 15 is most active to reduce the higher harmonic voltages and the voltage peaks resulting therefrom across certain points of the reactor, as well as the phase shift between supply voltage and output voltage, as will be discussed more in detail hereinafter.

Operation

As mentioned hereinabove, the use of the basic circuit described in the aforementioned copending applications resulted in maintaining the voltage V_2 across the load leads 17—18 substantially constant regardless of changes within a predetermined range in the supply voltage V_1 across the leads 42—44.

The operation of this so-called basic circuit is described in the aforementioned copending applications but in order to more fully understand the importance and value of the present invention, it is deemed advisable to refer very briefly to the operation of the basic circuit.

Although the operation can be explained from the standpoint of the primary winding 20 having a certain number of "effective ampere turns," depending upon whether the ampere turns of the correcting winding 22 are either "aiding" or "opposing" the ampere turns of the winding 20, it is easier to describe the correcting winding as providing a voltage "*e*" (Fig. 3) appearing across the corners 34 and 38 of the bridge circuit, which is superposed on or "injected" into the voltage "E" (Fig. 3) so as to aid or oppose it (or do neither), depending upon the relationship of the impedances of the reactors in the bridge circuit.

Referring to Fig. 3, if we assume that the supply voltage V_1 is normal, if the load voltage V_2 is to be normal it is necessary that the supply voltage V_1 equal the induced voltage "E," i.e. that the superposed voltage "*e*" be substantially ineffectual.

Assuming that the voltage induced in the correcting winding 22 is in the direction so that the right-hand end thereof is at a higher potential than the left-hand end, the corner 32 of the bridge circuit will be at a higher potential than the corner 36.

However, if the D.C. currents from the power sources 50 and 58 (Fig. 2) are such that the impedances of all of the reactors 24, 26, 28 and 30 are equal (as shown diagrammatically in Fig. 3 by the four arms of the saturable reactor bridge being of equal length), the voltage drops across the reactors 24 and 30 will be the same; and, if they are in phase, the corners 34 and 38 will be at the same potential, and the adjusting or "injected" voltage "*e*" will be zero.

On the other hand, if the impressed voltage V_1 is above normal, it is necessary for the superposed voltage "*e*" to act in a direction to oppose it so that the voltage "E" will be less than voltage V_1. Under these conditions, the D.C. current supplied by power sources 50 and 58 (Fig. 2) are unequal, whereby the impedance of the reactors 24 and 28 are less than the impedance of reactors 26 and 30. Consequently, the corner 34 of the bridge circuit is at a higher potential than the corner 38 and the voltage "*e*" is subtracted vectorially from V_1. In like manner, if the supply voltage V_1 is below normal, the potential of the corner 38 is maintained above the potential of the corner 34, and therefore the voltage "*e*" aids the voltage V_1.

Up to this point it has been assumed that the voltage drops across the bridge reactors are cophasal. These conditions were assumed in order to simplify the theoretical explanation. The assumption of cophasal relations between the voltage drops across the bridge reactors is very nearly satisfied when the current flowing in the primary of the transformer is small in comparison with the current flowing in the reactors. However, in reality, these cophasal voltage conditions exist only rarely. When the transformer is loaded, the voltages across the different reactors are no longer cophasal and the voltage relations become much more complex. For example, when the four reactors have equal impedance values and the load current flowing through the corners 34 and 38 is cophasal with the voltage across the leads 48 and 46, the voltage "*e*" appearing across the corners 34 and 38 of the bridge is approximately at right angles to the voltage across the leads 46 and 48 of the winding 22, or approximately at right angles to the voltage "E" across the winding 20 (Fig. 4). In this case, the voltage "E" practically equals the voltage V_1 in spite of the fact that the voltage "*e*" appears across the corners 34 and 38 of the bridge.

If the values of the reactances are such that the ratio of the reactance of the reactor 26 to the reactor 24 and the ratio of the reactance of the reactor 30 to the reactor 28, is rather small, the voltage "*e*" across the corners 38 and 34 of the bridge attains a nearly cophasal relationship with respect to the voltage across the leads 46 and 48 of the correcting winding 22, and with respect to the voltage "E" across the windings 20. This is illustrated in Fig. 4 wherein the path of the end of vector "*e*" is shown when the impedances of the bridge reactors are changed, as when the supply voltage varies from below normal to above normal. The path of the end of the vector "*e*" is shown as a parabola in Fig. 4 and this is most generally the case as determined by theoretical computations. However, in practice it has been found that the design constants usually are such that the height of the parabola is smaller than shown in Fig. 4 and the path of the end of the vector "*e*" approaches that of a circle.

Thus, under the conditions where "E" equals V_1 and the bridge circuit is in balance with the impedances of the various reactors being equal, the superposed voltage "*e*" is not required, but, being present at right angles to "E" it results in a phase displacement between "E" and V_1. Consequently, under conditions where supply voltage V_1 is normal, it is advisable to reduce the magnitude of the

voltage "e" to a minimum, and that is one of the functions of the suppressor reactor **78**. If the impedance of the suppressor reactor **78** were reduced to zero, so as to provide a short circuit between corners **34** and **38**, there would clearly be no phase displacement between V_1 and "E."

Turning next to a consideration of the form of the reactance curve for the suppressor reactor **78**, Fig. 5 shows the manner in which the D.C. currents to the various saturable core reactors vary as a function of the supply voltage V_1. Curves "A" and "B" are similar to like curves shown in copending application, Serial No. 497,978, and are dependent upon the characteristics of the amplifiers **50** and **58** and the voltage detector **74**. Curve "C" shows the most suitable D.C. current values for the suppressor reactor as found by manually changing the excitation of the D.C. winding of the suppressor reactor until the most favorable excitations were determined as functions of the supply voltage.

However, inasmuch as we are primarily interested in changes in the impedance of the various reactors, Fig. 6 shows the reactance curves for the same reactors plotted against percent normal supply voltage V_1. Thus, it will be noted that curves "A'" and "B'" for the two sets of reactors in the bridge circuit cross at 100 percent normal supply voltage, whereby the impedances of both sets of reactors are equal and the Wheatstone bridge is balanced, i.e. "E" equals V_1. Because there is no need for a superposed or injected voltage "e" under these conditions, the impedance of the suppressor reactor **78** (curve "C'") at such time is at a minimum.

If the impedance of the suppressor reactor **78** could be decreased to zero at normal supply voltage, there would be, in effect, a short circuit across the corners **34** and **38**; the superposed voltage would therefore be zero, and there would be no phase displacement whatsoever between V_1 and "E." This condition is approached very closely by the instant construction. During an actual test, the value of "e" was reduced from 7.5% of the load voltage to 2.2% thereof using a saturable core reactor of this type.

On the other hand, where the supply voltage V_1 is above or below normal, the superposed voltage "e" performs a useful function, and, during those conditions the D.C. excitation of the suppressor reactor **78** is at zero or a very low value (Fig. 5, curve "C") so that its A.C. impedance is maintained very high (Fig. 6, curve "C'").

As previously mentioned, the suppressor reactor **78** also reduces the higher harmonics in the bridge circuit and in the output voltage. The main objection to the presence of high harmonics resides in the fact that they interfere with telephonic communication. Also, the amount of interference is dependent upon the magnitude of the harmonic voltage as such and on the frequency of the harmonics (i.e. whether it is 3rd, 4th, 5th or 6th harmonic, and so forth) and not on the magnitude of the harmonic as compared with the total voltage.

Experience has shown that the harmonic voltages appearing across the A.C. windings of the reactors in the bridge, and especially across the corners **34** and **38**, reach their maximum when the supply voltage V_1 equals the voltage "E" and these higher harmonics are reflected by transformer action into the voltage induced in the secondary winding of the transformer **10**. It is during this condition that the low impedance reactor **78** across the corners **34** and **38** greatly reduces these higher harmonics.

The same holds true for the suppression of higher harmonics in the individual reactors in the bridge circuit. In addition, the use of the suppressor reactor **78** appreciably reduces the peaks of the voltage waves across the individual reactors because they are the result of the high harmonic voltages. For example, in one transformer when the suppressor reactor **78** was not used, an oscilloscope showed that the voltage wave across the individual reactors was rather steep and decidedly distorted with a rather high peak value. When the suppressor reactor **78** was used, the wave form was smoothed out and the peak was only 58% of the voltage peak without the suppressor reactor **78**.

It was also learned that the R.V.A. required by the control system using the suppressor reactor were, for most of the load conditions, less than required when the additional reactor was not used. This was especially outstanding when the supply voltage V_1 was normal.

During one test, the following results were observed:

Reactor	Volts	Amps.	R.V.A.
24 (and 28)	176	1.76	310.
26 (and 30)	187	.8	150 or (150+310)×2= 920 R.V.A.

Reactor	Volts	Amps.	R.V.A.
24 (and 28)	128	.9	115.
26 (and 30)	127	.5	63.5.
78	88	1.68	198 or (115+63.5)×2+ 198=555 R.V.A.

Thus, when the suppressor reactor **78** was used the R.V.A. was 555 and when it was not used the R.V.A. was 920.

Thus, it is apparent that there has been provided a novel harmonic suppressor which fulfills all of the objects and advantages sought therefor. It maintains the output voltage and the voltage across the individual reactors in the bridge circuit substantially free of higher harmonics which would normally interfere with telephonic communication.

It also reduces the voltage peaks across the individual bridge reactors.

Furthermore, it materially reduces the phase displacement between the impressed voltage and the output voltage when the supply voltage is normal.

In addition, it reduces the reactive kva. consumed by the reactor Wheatstone bridge, and thus the total reactive kva. input into the transformer circuit is decreased, especially when the supply voltage is normal.

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 regulating device containing a main transformer winding and a correcting winding; a Wheatstone type bridge circuit comprising at least four impedances connected together to provide two sets of opposed corners and two sets of opposed impedances; means connecting one side of the main winding to one lead of a set of leads; means connecting one set of opposed corners of the bridge circuit in series circuit between the other side of the main winding and the other lead of said set of leads; means connecting the correcting winding across the other set of corners; and means for varying the magnitude of at least one set of impedances; the improvement which comprises a variable impedance connected across said one set of corners and characterized by the fact that the value of the impedance is at a minimum when the bridge circuit is balanced.

2. In a voltage regulating device containing a main transformer winding and a correcting winding; a Wheatstone type bridge circuit comprising at least four saturable reactors connected together to provide two sets of opposed corners and two sets of opposed reactors; means connecting one side of the main winding to one lead of a set of leads; means connecting one set of opposed corners of the bridge circuit in series circuit between the other side of the main winding and the other lead of said set of leads; means connecting the correcting

winding across the other set of corners; and means for varying the impedance of at least one set of reactors; the improvement which comprises means for suppressing harmonic components in the device, said last named means including an impedance connected across said one set of corners of the bridge circuit; and means for varying the value of said impedance, to reduce the value thereof to a minimum when the bridge circuit is substantially balanced.

3. In a voltage regulating device containing a main transformer winding and a correcting winding; a Wheatstone type bridge circuit comprising at least four impedances connected together to provide two sets of opposed corners and two sets of opposed impedances; means connecting one side of the main winding to one lead of a set of leads; means connecting one set of opposed corners of the bridge circuit in series circuit between the other side of the main winding and the other lead of said set of leads; means connecting the correcting winding across the other set of corners; and means for varying the magnitude of at least one set of impedances; the improvement which comprises a saturable core reactor connected across said one set of corners and including a D.C. winding; and means for varying the magnitude of the current passing through said D.C. winding.

4. In a voltage regulating device containing a main transformer winding and a correcting winding; a Wheatstone type bridge circuit comprising at least four saturable core reactors connected together to provide two sets of opposed corners and two sets of opposed reactors; means connecting one side of the main winding to one lead of a set of leads; means connecting one set of opposed corners of the bridge circuit in series circuit between the other side of the main winding and the other lead of said set of leads; means connecting the correcting winding across the other set of corners; and means for varying the impedance of at least one set of reactors; the improvement which comprises a saturable core reactor connected across said one set of corners and including a D.C. winding; and means for varying the magnitude of the current passing through said D.C. winding so that the impedance of said last named reactor is at a minimum value when the bridge circuit is balanced and at a higher value when the bridge circuit is in an unbalanced condition.

5. In an electric control device, the combination of power input and output circuits; a bridge circuit comprising at least four saturable core reactors connected together to provide two sets of opposed corners and two sets of opposed reactors; means including one set of opposed corners for connecting said bridge circuit in series circuit between the power input and output circuits; means connecting a source of voltage across the other set of opposed corners; means for varying the impedance of at least one of said reactors; a variable saturable core reactance device connected across said one set of opposed corners; and means for varying the reactance of said device so that the reactance thereof is at a minimum value when the bridge is substantially balanced and at a higher value when the bridge is in an unbalanced condition.

6. In an electrical control system comprising a bridge circuit having input and output terminals, means for supplying a voltage to the input terminals, and means for controlling the balance conditions of the bridge circuit to provide a variable voltage at the output terminals, the improvement comprising a variable impedance device connected in a circuit between the output terminals of the bridge, and means for controlling the impedance of said device in accordance with the balance conditions of the bridge circuit for reducing the impedance of the device to a minimum value when the bridge is substantially balanced and for increasing the impedance of the device when the bridge is in an unbalanced condition.

7. In an electrical control system comprising a power output circuit, a power input circuit connectable to a supply source for supplying power to the power output circuit, a bridge circuit having input and output terminals, means for supplying a voltage to the input terminals, means for controlling the balance conditions of the bridge circuit to provide a variable voltage at the output terminals, and means connecting the output terminals of the bridge circuit in series circuit relation with one of said power circuits, the combination therewith of a variable impedance device connected in a circuit between the output terminals of the bridge, and means for controlling the impedance of said device in accordance with the balance conditions of the bridge circuit so that the impedance of the device is at a minimum value when the bridge is substantially balanced and at a higher value when the bridge is in an unbalanced condition.

8. In an electrical control system comprising a bridge circuit including bridge input and output terminals, at least two saturable reactors each connected in a different arm of the bridge, means for supplying a voltage to the bridge input terminals, and means for varying the impedance of said reactors to control the balance conditions of the bridge circuit, the combination therewith of an additional saturable reactor having a reactance winding and a control winding, means connecting said reactance winding in a circuit between the output terminals of the bridge, and means including a source of control current connected with said control winding for varying the impedance of said reactance winding so that the impedance thereof is at a minimum value when the bridge circuit is substantially balanced.

9. In an electrical control system comprising power input and output circuits, a bridge circuit comprising bridge input and output terminals and including at least two saturable core reactors each having a reactance winding and a control winding, each of said reactance windings being connected in a different arm of the bridge circuit, means for impressing a voltage across the bridge input terminals, means connecting the output terminals in a circuit in series between said power input and output circuits, and means for supplying control current to the control winding of each of said reactors to control the balance conditions of the bridge circuit, the combination therewith of means for suppressing harmonic components in the system, said last named means comprising an additional saturable core reactor having a reactance winding and a control winding, means connecting the last named reactance winding in a circuit between the output termials of the bridge circuit, and means including a source of control current connected with the last named control winding for varying the impedance of said last named reactance winding so that the impedance thereof is at a minimum when the bridge circuit is substantially balanced and at a higher value when the bridge circuit is in an unbalanced condition.

10. In an electrical control system comprising a power output circuit and a power input circuit connectable to an A.C. source for supplying power to the power output circuit, a bridge circuit comprising bridge input and output terminals, at least two saturable core reactors each having an A.C. reactance winding and a D.C. control winding, said reactance windings each connected in a different arm of the bridge, means for supplying an A.C. voltage to the input terminals, means connecting the output terminals in a circuit in series with one of said power circuits, and means for supplying D.C. control current to the control winding of each of said reactors to control the balance of the bridge circuit, the combination therewith of an additional saturable core reactor having a reactance winding and a control winding, means connecting the last named reactance winding in a circuit between the output terminals of the bridge, means for supplying D.C. current to the last named control winding, and means for controlling the current in said last named control winding in accordance with the balance conditions of the

bridge circuit for maintaining the impedance of said last named reactance winding at a minimum when the bridge circuit is substantially balanced and for increasing the impedance thereof to a higher value when the bridge is in an unbalanced condition.

11. In an electrical control system, the combination of a transformer including a main winding and a correcting winding, a bridge circuit comprising bridge input and output circuits, at least two saturable core reactors each having an A.C. reactance winding and a D.C. control winding, each of said reactance windings being connected in a different arm of the bridge circuit, means connecting said bridge input circuit with said correcting winding, means connecting said bridge output circuit in series with said main winding, means for supplying control current to the control winding of each of said reactors to control the balance of the bridge circuit, and means for suppressing harmonic components in the system, said last named means including an additional saturable core reactor having an A.C. reactance winding and a D.C. control winding, means connecting the last named reactance winding across the bridge output circuit, and means including a source of D.C. control current connected with the last named control winding for varying the impedance of said last named reactance winding so that the impedance thereof is at a relatively low value when the bridge is balanced and at a higher value when the bridge is in an unbalanced condition.

12. In an electrical control system, the combination of a transformer including main primary and secondary windings and a correcting winding, a bridge circuit comprising bridge input and output circuits, at least two saturable core reactors each having an A.C. reactance winding and a D.C. control winding, each of said reactance windings being connected in a different arm of the bridge circuit, means connecting said input circuit with said correcting winding, means connecting said output circuit in series with one of said main windings, means for supplying D.C. current to the D.C. control winding of each of said reactors to control the balance conditions of the bridge circuit, and means for suppressing harmonic components in the system, said last named means including an additional saturable core reactor having an A.C. reactance winding and a D.C. control winding, means connecting the last named reactance winding across said output circuit, and means including a source of D.C. current connected with the last named D.C. winding for varying the impedance of said last named reactance winding so that the impedance thereof is at a minimum value only when the bridge circuit is substantially balanced.

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