

Oct. 28, 1952

P. GLASS

2,615,936

VARIABLE TRANSFORMER CONTROL

Filed March 31, 1949

2 SHEETS—SHEET 1

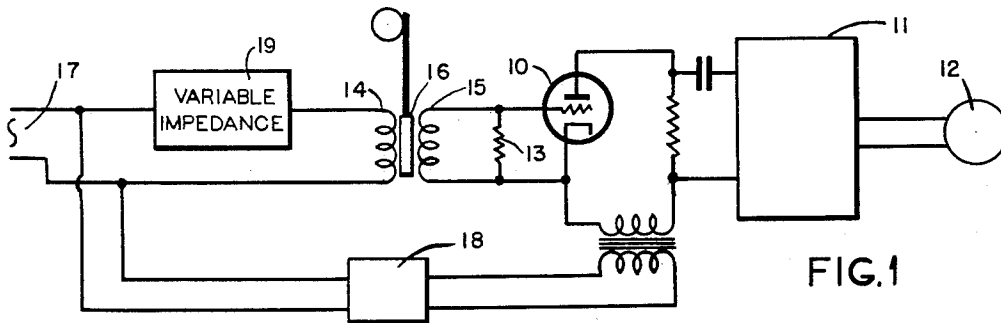


FIG. 1

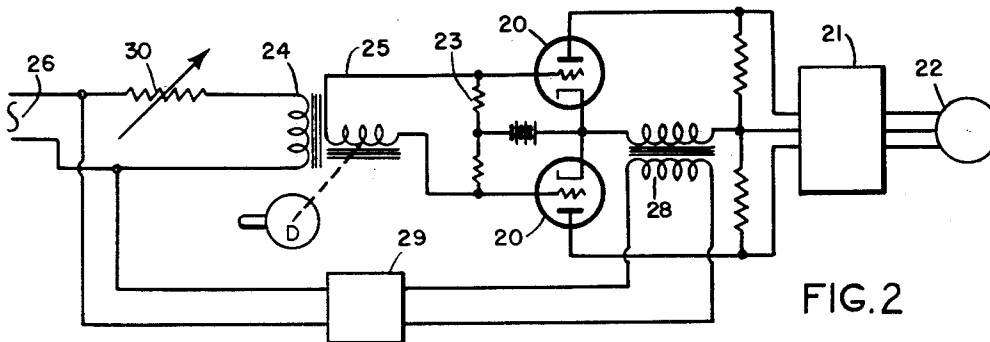


FIG. 2

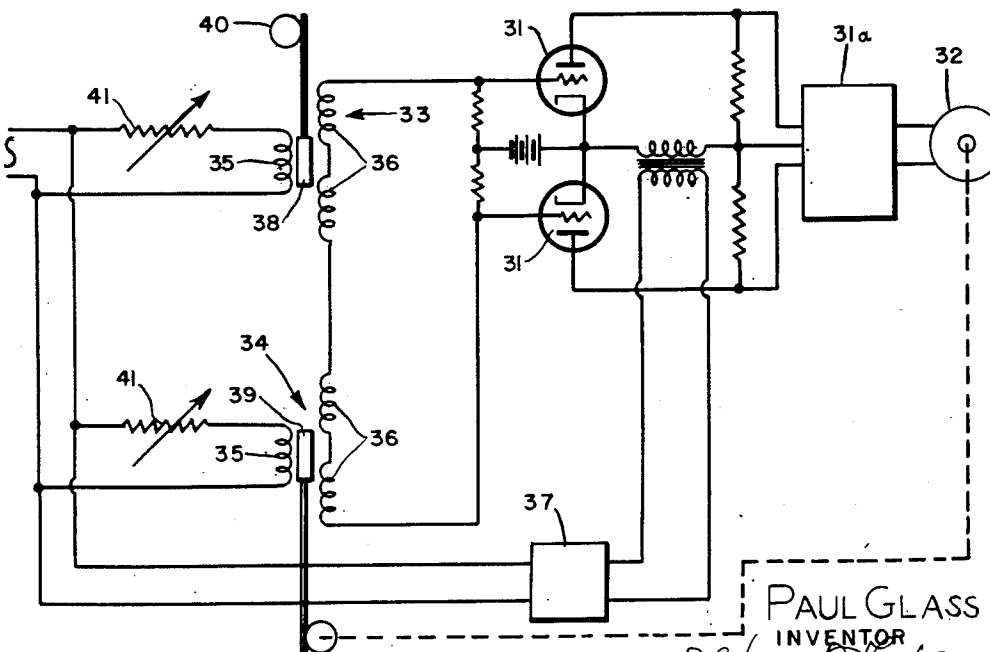


FIG. 3

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2 SHEETS—SHEET 2

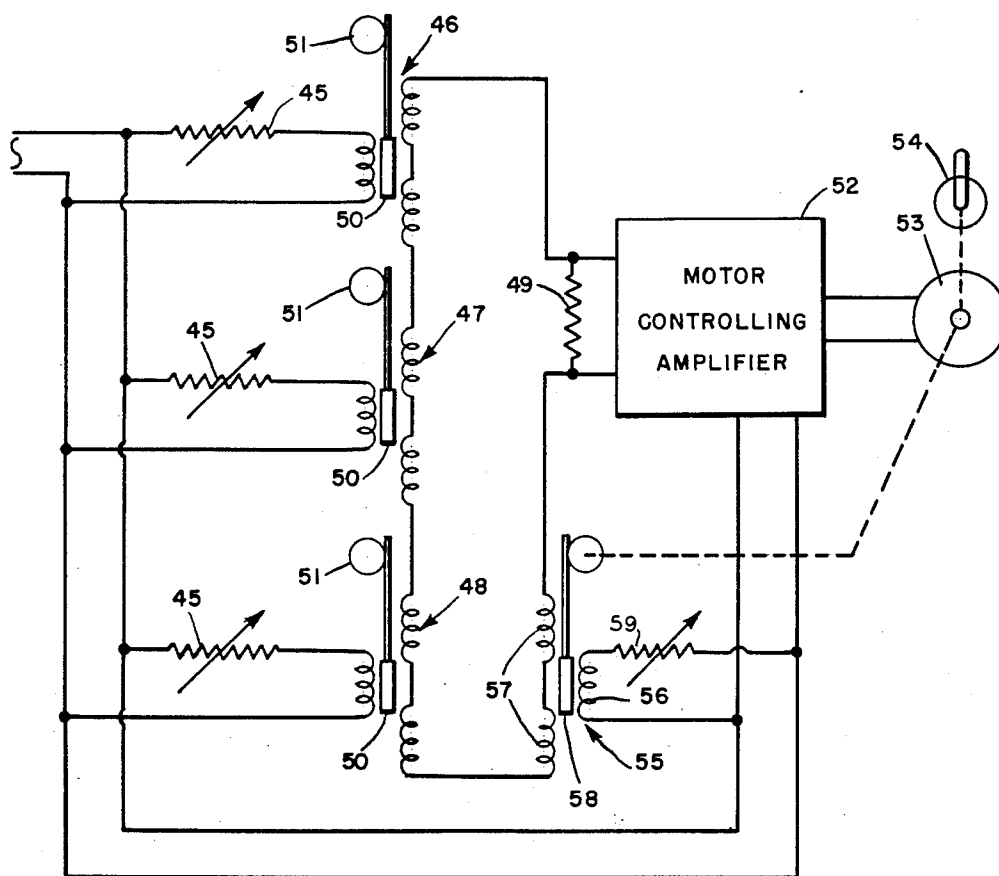


FIG. 4

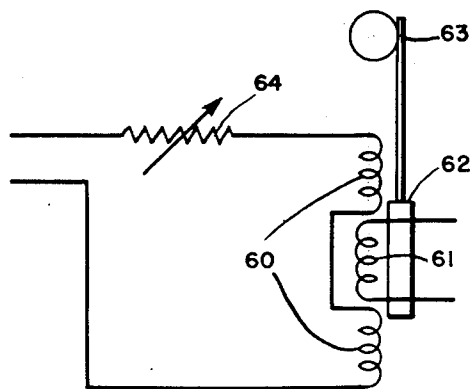


FIG. 5

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VARIABLE TRANSFORMER CONTROL

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3 Claims. (Cl. 171-119)

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This invention relates to variable inductive coupling devices of the kind having an alternating current input to a primary inductance a secondary inductance coupled to the primary inductance, and mechanically operable means for varying the degree of coupling between the primary and secondary to vary the amplitude of secondary voltage.

Such devices have been developed in a wide variety of forms and used in many ways for widely varying applications. It has been recognized that their fields of utility can be extended still further by providing, additional to the means for varying inductive coupling between the primary and secondary, a means for introducing a second variable control for selection of the range of voltage variations produced by the coupling varying means.

For example, in telemetering motor control, a device of the kind in question may have its coupling varying mechanism actuated by a controller, and its output voltage applied as a signal to an amplifier that controls motor operation. Provision of the inductive device in such a system with second means for controlling its output voltage, may be used as a sensitivity selector by means of which may be selected the degree of response of the output motor to a given variation of coupling between the primary and secondary of the inductive device.

Another possibility of valuable use of such a second control is that it provides for introduction into a voltage controlling device of a second variable, by means of which the utility of systems controlled by such devices can be greatly extended.

It has been proposed to accomplish these desirable results by variably loading the secondary of the inductive device, specifically by applying across the output a by-pass or bleeder variable resistance, the selected value of which determines the amplitude of output voltage with a given degree of inductive coupling between primary and secondary as imposed by the mechanical signal input controlling such coupling. While such expedient is effective to accomplish the primary purposes of selecting the amplitude of the output voltage, or of providing for introduction of a second variable to control such voltage, the provision of a variable resistive load in the output of the secondary affects the phase of the output voltage, particularly if the impedance that the circuit works into is low. In many situations such a phase shift cannot be tolerated. In certain applications multiple voltage controlling devices of the kind in question are connected in a

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single circuit, the output of which is a summary of the variable voltage outputs of the different devices. In certain applications one or more such devices comprise signal voltage generators supplying input circuits of alternating current amplifiers. In either case, variation of the phase accompanying variation of amplitude of the signal voltage produced by the device or devices, produces loss of the phase agreement between voltages that prevents accurate response of the system.

The primary object of the invention is the provision of a variable coupling inductive voltage controlling device with second means for controlling the amplitude of its output voltage that will not be accompanied by phase shift of such voltage, regardless of the magnitude of impedance of the load supplied by the device.

Another object is the provision of a variable coupling transformer having provision for a mechanical signal input to vary coupling between its primary and secondary, with a second signal input means effective to vary the amplitude of secondary voltage without shift of phase of such voltage.

The accompanying drawings illustrate application of the invention to various types of variable coupling inductive voltage controllers, and suggest various fields of use for such devices. In such drawings, all of which are schematic:

Fig. 1 shows the invention applied to a simple variable transformer in a simple motor speed control circuit.

Fig. 2 shows a different sort of transformer used in a similar circuit.

Fig. 3 shows the invention applied to a signal bridge circuit that comprises the input of a servomotor powered position control system.

Fig. 4 shows the invention applied to a summarizing circuit that may be used to summarize six variables.

Fig. 5 is a schematic of a different type of variable transformer to which the invention may be applied.

Referring first to Fig. 1, the reference numeral 10 indicates an alternating current amplifier stage that may be taken as being a well-known type, and that is followed by additional electronic equipment 11 including a motor control stage for selecting the speed of the motor 12 in accordance with the amplitude of an alternating signal voltage applied to its grid circuit 13. A signal for this input circuit is generated by a variable transformer having a primary 14, a secondary 15 and a movable core 16 of a magnetically permeable

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material, the position of which is variable relative to the windings 14 and 15 to vary the degree of coupling between them.

The primary of the transformer is energized by a source of alternating current 17 and as indicated, the amplifier tube 10, has its anode circuit energized from the same source, so that the phase of anode voltages of the amplifier stages are correctly related to the phase of the voltage supplied through the transformer to the input circuit 13, a phase shifting device at 18 permitting synchronization of the anode voltage with the output voltage of secondary winding 15.

In the system so far described, a variation of the position of the core 16 proportionally varies the amplitude of the alternating signal voltage applied to the input circuit 13, resulting in a change of the conduction of the tube 10, and through the motor control unit 11, varying the speed of the motor 12.

In addition to the signal input provided by the movable core 16, it may be desirable to provide for a second input signal. For example, the sensitivity of the control effected by the member 16 may have to be varied so that for a given movement of the member 16 a different variation of the speed of the motor 12 will be accomplished. However, provision of a variable resistance across the output terminals of the secondary will be accompanied by a shift if phase of the signal voltage, particularly in the case that the amplifier input circuit is a low impedance circuit, resulting in loss of synchronization between anode and signal voltages, and accuracy of control of the output of the tube 10 will be impaired. The invention provides for a second signal input to the transformer without altering the phase of its output voltage, by providing in series with the primary 14 a variable impedance 19 by means of which variation may be accomplished in the voltage drop across the primary 14. The value of impedance 19 should be sufficiently high, as compared with the impedance of the primary winding 14, to give to the primary circuit including winding 14 the impedance characteristic of the variable impedance 19 throughout the range of variation of the latter. This large value of the variable impedance serves to maintain constant the phase of the primary and secondary voltages during operation of the transformer to produce various secondary output voltages. It will be readily apparent that with such unequal values of the impedance 19 and primary winding, variation of the value of the impedance will be effective to vary the voltage drop across winding 14 but will constitute such a small variation in the relation of the two impedances that no appreciable phase shift of the voltage across the winding will occur. Consequently, since the values of the range of variation of the impedance are sufficiently large to maintain a fixed phase relation between an energizing voltage applied to the impedance 19 and primary winding 14 and the voltage appearing across the primary winding, the phase of the output voltage of the secondary 15 will remain constant, although its amplitude may be varied widely by variation of the value of impedance 19. It will be appreciated from consideration of Fig. 1, that the provision of a variable impedance across the terminals of the secondary 15, although effective to vary the amplitude of the output voltage, would result in shift of phase of the output voltage accompanying variation of such impedance, especially in the case of a low impedance input to

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the amplifier 10. One of the values of the present system, as illustrated by Fig. 1 is that it is of universal application, that is to say, it may be applied in any situation regardless of the impedance value of the input of the circuit energized or controlled by the secondary winding of the variable transformer.

In Fig. 2, a similar circuit is shown; but in this case the amplifier stage comprising tubes 20 may be taken to be a phase discriminating amplifier, the output of which controls through additional electronic equipment 21, not only the speed but also the direction of the motor 22, in accordance with 180° phase reversal and amplitude of an alternating voltage of input circuit 23.

In this form of the invention, the variable signal generator comprises a transformer having a primary winding 24 and a secondary winding 25 that is mounted for rotation relative to the primary winding 24, as by a director D so that not only the degree of coupling may be varied, but the phase sense of the output voltage may be reversed. In this system, opposite ends of the secondary winding 25 are connected with the control grids of the respective amplifier tubes 20, so that voltages of opposite phase are applied to such grids, and amplitude as well as phase sense of such voltages may be selected by rotation of the secondary 25 relative to the primary 24. Anode voltages are supplied to tube 20 from the same source 26 that supplies primary 24, through a transformer 28 coupled in a common return, so that anode voltages of the two tubes are in phase, which may be adjusted to synchronization with the output voltage of the secondary winding 25 by a phase shifter 29. This circuit, which is of itself well known, is so arranged that the tube 20, of which the control grid voltage is in phase with the anode voltage, will conduct to a degree determined by amplitude of the signal voltage. The identity of the tube so conducting determines the direction of motor operation, and the signal voltage amplitude, determined by the degree of coupling between primary 24 and secondary 25, selects the speed of its operation.

As in the case of the system of Fig. 1, it may be desirable to alter the sensitivity of the system, that is the variation in motor speed resulting from a given degree of rotation of the secondary 25. A phase shift of the signal voltage, which would result from varying the load on the secondary to vary the signal voltage, would involve loss of accurate motor speed control, due to loss of synchronization of the controlling signal and anode voltages. As in Fig. 1, change of sensitivity without phase shift of the signal voltage can be accomplished by adjustment of a variable impedance, shown as a variable resistor 30, connected in series with the primary 24, of large value compared to the primary winding 24, and by means of which selection may be accomplished of the voltage drop across the primary.

In Fig. 3, a phase discriminating variable voltage alternating current amplifier stage comprises tubes 31 and controls a motor-actuating circuit 31-a that selects the direction of operation of a motor 32. The input circuit of the amplifier tubes 31 comprises two variable differential transformers 33 and 34. Each of these transformers comprises a primary winding 35 and a pair of secondary windings 36 that are so connected that when the two windings constituting a secondary are equally coupled to the primary, their output voltages are equal and opposed, and there is no resultant output voltage across the second-

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ary. However, on variation of the coupling between the respective secondary windings and the primary, one secondary voltage will overcome the other and a resultant output will appear. The secondaries of the transformers 33 and 34 are connected in series, so that the output voltages of the secondaries of the two transformers may aid or oppose each other, depending on the polarities of such outputs as determined by the degree of coupling between the split windings and primary of each. The primaries of the transformers 33 and 34 are energized by a source of alternating current that may also supply power to the anodes of tubes 31. As shown, the anode voltages are applied in phase agreement, and their phase may be controlled by a phase shifter 37, adjustable to synchronize the anode and signal voltages. Coupling between the primaries and secondaries of the transformers 33 and 34 is governed by two movable magnetically permeable core elements 38 and 39. The transformer 33 may be taken as the signal or transmitter device, and transformer 34 as a follow up or feedback device. The core 38 of transformer 33 may be moved by a controlling device 40, while the core element 39 of the feedback transformer is operated through a mechanical connection with the motor 32. This circuit, which is well known, is so arranged that upon displacement of the core element 38 a signal voltage is applied to the amplifier input, causing one or the other tube 31 to conduct, to operate the motor 32 in a proper direction to drive the core element 39 of the receiver transformer 34 to a position to restore the bridge balance and stop operation of the motor.

The invention may be applied to this type of circuit by connecting in series with either or both primaries 25 of the transformers 33 and 34 a variable resistance 41 in the manner indicated. Variations of either or both of these resistances provide a means whereby the response of the motor—that is to say the degree of operation as a result of a given movement of the movable core 38 of transformer 33—may be selected.

Fig. 4 illustrates a somewhat different application, whereby a different use is made of the possibility of altering the normal relation between the output voltage of a variable transformer by a resistance coupled in series with its primary. A series of such transformers, each with a resistance 45 coupled in series with its primary, is shown at 46, 47 and 48. These transformers have opposing paired secondary windings, as disclosed in Fig. 3, the secondaries of the respective transformers being connected in series, so that a resultant of their respective output voltages appears across an output resistor 49. As also described in connection with Fig. 3, the secondaries of these transformers are coupled to their respective primaries by movable magnetically permeable core elements 50, each of which is individually movable by a controller 51, so that the relative degree of coupling of the respective parts of the secondary of each transformer to its primary may be selected by movement of the elements 50, and output voltages of the secondaries of the respective transformers thereby selected. The provision of the variable resistance 45 in each of the primary circuits provides means whereby may be selected the value of resultant voltages appearing across the secondary of each transformer when the halves of the secondary windings are unequally coupled to the primaries to given degrees.

The resultant voltage of all the transformer

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secondaries is reversible in phase and variable in amplitude, depending on the sums of the resultant voltages of each split secondary. The circuit is shown as controlling the input or signal voltage to a phase-discriminating motor-controlling amplifier 52 that is arranged to operate a controlled motor 53 in a direction determined by the phase of the signal voltage, and driving a device such as a summarizing indicator 54. To enable the motor 53 and indicator 54 to assume a definite position that is accurately related to the sum of the various secondary voltages, a feedback transformer 55 is provided. This transformer is similar to the signal generating transformers previously described, comprising a primary winding 56 energized by the same current source that energizes the signal transformers, and a split secondary having windings 57 connected in series opposition, and in series in the amplifier signal circuit. A movable core member 58 is driven by the motor 53, and the arrangement is such that when operation of the motor has reached a degree proportional to the amplitude of the signal that instituted such operation, the output of the feedback transformer 55 will cancel the resultant voltage produced by the signal transformers.

This circuit provides a means of solving an equation of the type $R=k(ab+cd+ef)$. The letters a, b , etc., represent values of variables selectable by variation of the resistances 45, and by variations of the positions of the core elements 50, while the letter k indicates a constant determined by variation of the output of the feedback transformer produced by a given degree of rotation of the motor 53. The value of the constant k may be selected by changing the effective resistance of a variable resistor 59 connected in series with the primary winding of the feedback transformer 55. It is to be noted that in this arrangement, positions of the movable core elements 50 wherein the two parts of the respective secondary windings are equally coupled to the respective primaries, are zero positions, wherein variation of the resistances 45 has no effect in production of an output voltage across the entire secondary.

In Fig. 5 a type of variable transformer different from those described above, is shown having the invention applied to it. In this application, the transformer comprises a divided primary winding 60 and a secondary winding 61 carried by a movable support 62 and being thereby movable relative to the primary, as by a mechanical controller member 63, to vary its coupling to the respective windings of the primary. As in the other forms of the invention, a variable resistance 64 is connected in series with the primary winding, so that the voltage drop across the primary winding may be varied. The purpose of this resistance is as already described, to provide a means of variation of the changes in amplitude of the output voltage of the secondary winding 61 due to changes in its position relative to the primary.

In the foregoing have been disclosed two typical applications of the invention, where it is desirable to provide in a variable transformer type of voltage regulator a second means for varying the output voltage. In one such application, illustrated by Figs. 1, 2 and 5, a single variable transformer is provided with second means for controlling its output voltage while maintaining a predetermined phase relation to voltage in a following alternating current circuit. In the second type of application, illustrated by Figs. 3 and

4, plural variable transformers having secondaries connected in a common circuit, are provided with second means for controlling amplitude of their output voltages without disturbing relation of the phase of the respective secondary voltage to each other. Obviously, the invention is applicable in any situation where the output of a variably coupled transformer must be maintained in phase synchronization with a second voltage, and such transformer is to have means additional to variable coupling between its primary and secondary for selecting amplitude of its output voltage.

Accordingly, it is to be understood that the above descriptions are for purposes of disclosure only and are not to be interpreted as limiting the scope of the invention as set forth in the appended claims.

I claim:

1. A voltage amplitude regulator comprising inductively coupled primary and secondary windings, a core piece assembled with said windings and movable relative to them to vary the coupling between said primary and secondary windings to select the amplitude of output voltage of the secondary winding, and second means for varying the amplitude of output voltage of the secondary winding comprising a variable resistance having a single output tap connected only with one side of said primary winding, a single input tap for connection with a single side of a signal source, and adjustable resistance means series connected between said taps for selecting the value of resistance that is effective between them, said adjustable resistance means having a value sufficiently large with respect to impedance of said primary winding to maintain a fixed phase of voltage applied to said primary winding.

2. In an electrical system including two associated electrical devices respectively having alternating current energizing inputs for energization by phase synchronized voltages, and at least one of said devices being a variable transformer having a primary winding constituting its said energizing input, a secondary winding inductively coupled to such primary winding, and a core piece assembled with said windings and movable rela-

tive to them for varying the degree of such coupling to vary amplitude of the output voltage of the secondary winding; second means for varying the amplitude of such output voltage while maintaining constant its phase comprising a variable resistance having only a single output tap connected only with one side of said primary winding, a single input tap for connection to a single side of a signal source, and variable resistance means series connected between said taps, said variable resistance means having a value sufficiently large with respect to impedance of said primary winding to maintain a fixed phase of voltage applied to said primary winding.

3. In an alternating voltage circuit comprising plural variable transformers, each having a primary winding, a secondary winding inductively coupled to its primary winding, and mechanically operable means for varying the degree of coupling between its primary and secondary winding; means for varying the degree of change of amplitude of secondary voltage responsive to operation of the coupling-varying means of at least one said transformer while maintaining constant its phase when the primaries of said transformers all are energized by phase synchronized voltages, comprising a different variable impedance connected in series with the primary winding of each of said transformers, said impedances respectively having values sufficiently large relative to the primary windings with which they are connected to maintain a fixed phase of voltage applied to said primary winding.

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