Nov. 26, 1963 E. E. MOYER 3,112,440

FERRORESONANT VOLTAGE STABILIZER

Filed Jan. 8, 1962 3 Sheets-Sheet 1

Fig. 2

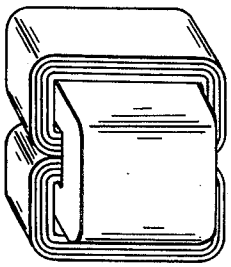


Fig. 1

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Filed Jan. 8, 1962 3 Sheets-Sheet 2

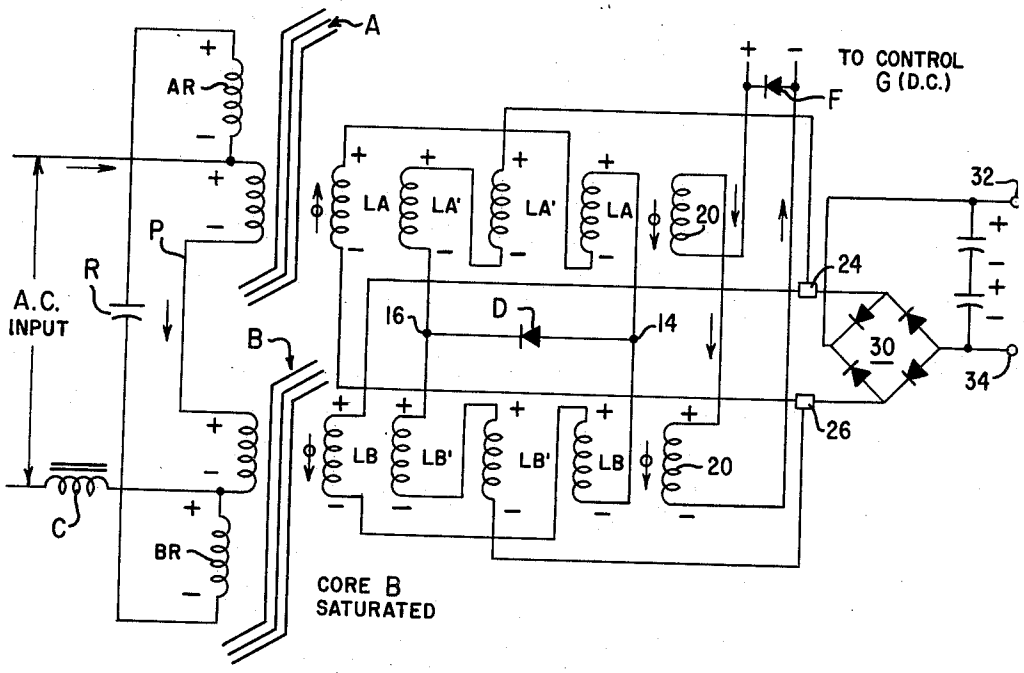


Fig. 3

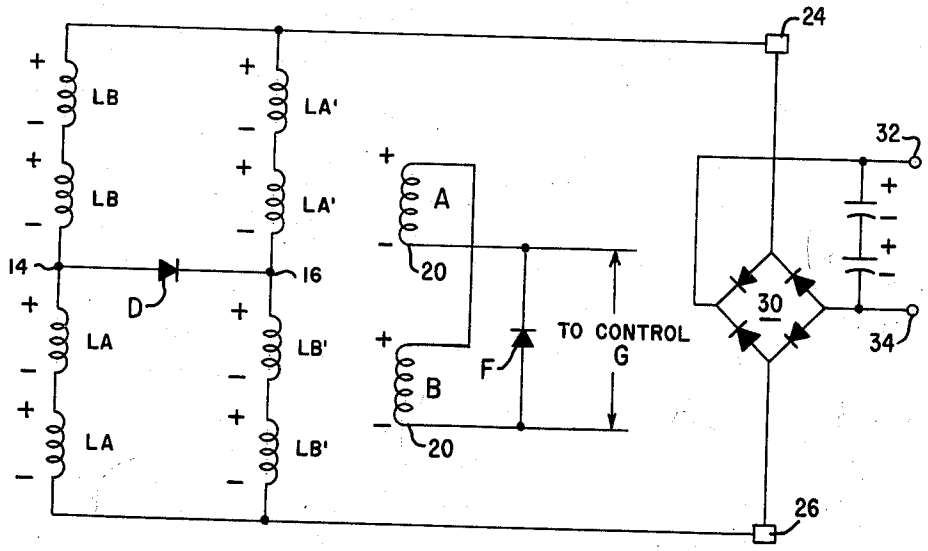


Fig. 4

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Filed Jan. 8, 1962 3 Sheets-Sheet 3

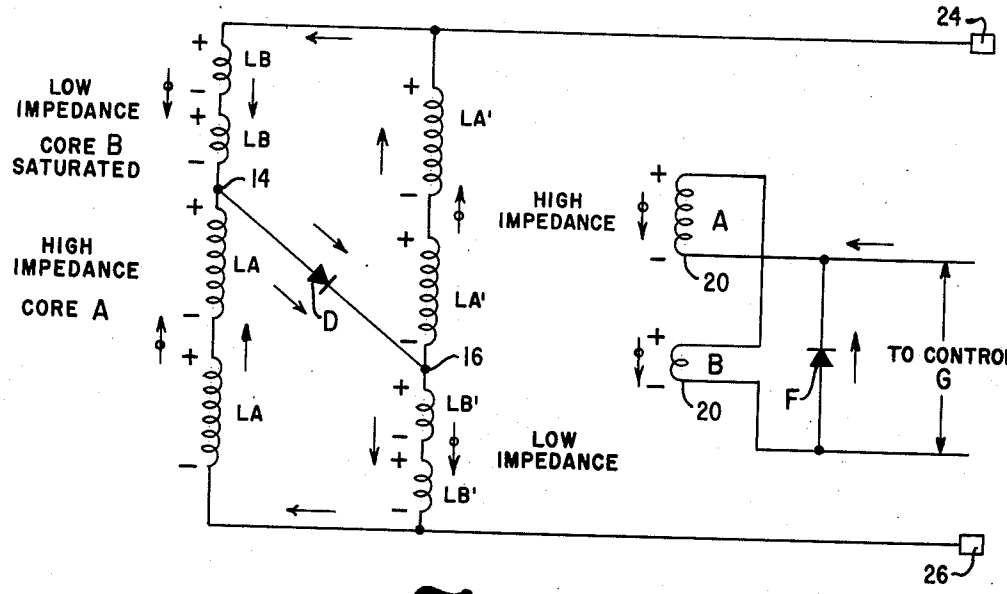


Fig. 5

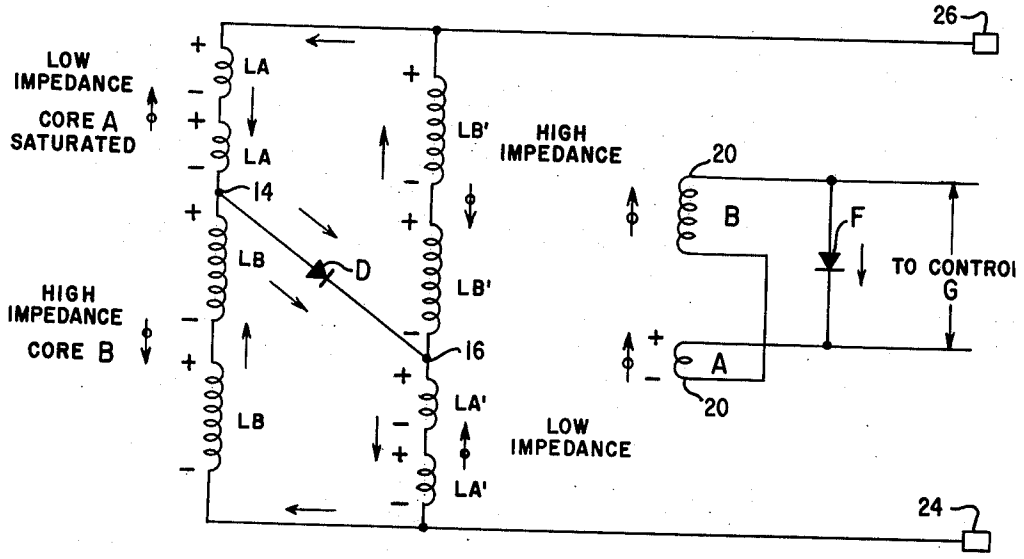


Fig. 6

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FERRORESONANT VOLTAGE STABILIZER

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Filed Jan. 8, 1962, Ser. No. 164,927
9 Claims. (Cl. 323—56)

This invention relates to voltage-regulating devices, more particularly to voltage-regulating devices using ferroresonant circuits controlled by a direct current.

Ferroresonant transformers of the type disclosed in Sola Patent No. 2,143,745 have been extensively used in the regulating field, but have not been entirely satisfactory; for one thing, their costs of construction have been high. In other cases, the physical size of the transformers have been too large for use in constricted places, especially where space is at a premium.

The present invention contemplates the provision of regulators having simplified forms, preferably using standard parts in their fabrication, which utilize ferroresonant circuits. Furthermore, the standard parts allow the regulators to be fabricated at lower costs, and also allow the best possible utilization of space, in that the parts can be separated without special consideration being given to their magnetic interaction or interrelation.

It is, therefore, a principal object of this invention to provide a regulating device utilizing ferroresonant circuits, which is fabricated from standard parts readily available in the trade.

It is a further object of this invention to provide a regulating device utilizing standard transformer constructions, wherein two of the transformers are placed in cooperative electrical relation utilizing ferroresonant circuits, and wherein a direct current is utilized to control and regulate the voltage variations.

It is a further object of this invention to provide a voltage-regulating device utilizing ferroresonant circuits comprising several parts which cooperate together electrically, and yet are capable of being mounted in various spaced relations in a predetermined physical space without prejudicing their ability for regulating electrical currents.

Other objects and advantages of this invention relating to the arrangement, operation and function of the related elements of the structure, to various details of construction, to combinations of parts and to economies of manufacture will be apparent to those skilled in the art upon consideration of the following description and appended claims, reference being had to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

Referring to the drawings:

FIGURE 1 is a schematic diagram of connections showing a regulating device utilizing ferroresonant circuits with two transformers fabricated from standard transformer parts;

FIGURE 2 is an isometric view showing the physical appearance of one of the two transformers utilized in the circuit shown in FIGURE 1;

FIGURE 3 is a schematic diagram of connections showing the interconnections of the windings on the two cores shown in FIGURE 1;

FIGURE 4 is a schematic diagram of a portion of the circuit shown in FIGURES 1 and 3 when the output voltage is maximum with coil polarities corresponding to FIGURES 1 and 3;

FIGURE 5 is a schematic diagram similar to FIGURE 4 when one core is saturated; and

FIGURE 6 is a schematic diagram similar to FIGURE 5 in the succeeding half cycle of the alternating current with the second core saturated.

Referring to the drawings, particularly to FIGURE 1, a pair of ferromagnetic devices A and B are shown which are connected together with their windings in a pretermined relation to provide a regulating device which utilizes a ferroresonant circuit. The ferromagnetic devices are fabricated from standard transformer parts and appear in the form shown in FIGURE 2 similar to a standard shell-type transformer. The core of the ferromagnetic device is laminated in form to reduce eddy current losses and having a cross-sectional area which is designed, giving consideration to the ferroresonant features of the device, to enable it to become saturated under predetermined voltage and load conditions. Two of these devices are shown connected together in the diagram of connections shown in FIGURE 1 in cooperation with an A.C. choke C which is the equivalent of a linear reactor. The windings on the cores are identical in form, being provided with a primary circuit P having identical coils on each of the cores A and B as shown. The two primary coils are connected in series and also in series with the A.C. choke coil C. Connected to the primary coils, series aiding, auto-transformer fashion, is another pair of coils, AR and BR, identical in themselves, one positioned on each core A, B, which are connected in series with a fixed capacitor R to form a resonant circuit, half of whose inductance is contributed by the windings on each of the cores operating at the frequency of the alternating current in the primary circuit. The two coils in series with the capacitor R are connected in such a manner that the induced voltages in the separate coils are additive. This comprises the primary circuit of each of the ferromagnetic devices.

Superimposed on each primary winding of the cores A and B are two load windings LA and LA' connected in series, and LB and LB' in series, each with voltages additive, with the two pairs in parallel and with the center points of the parallel pairs of coils connected together by a bias or coupling diode D. This provides a load winding consisting of two parallel paths 10 and 12, each path consisting of a series connection of one winding from each of the two cores A and B connected with the voltage additive, with the two center points 14 and 16 of the two parallel paths serving as the points onto which the coupling diode D is connected. The load windings, in this way, are used as coupling windings, with the added advantage that the overall heating of the coils under load conditions is more uniform. These interconnections are diagrammed in the circuit of FIGURE 3.

Each of the cores A and B is provided with a control coil 20, which are connected in series in induced voltage opposition with both coils connected across a coupling diode F. The control coils are energized with direct current controlled by an electronic control device G responsive to the voltage at the load as will be described further hereinafter.

The load coils LA, LA' and LB, LB' are connected to terminals 24 and 26, which are connected to a bridge-connected rectifier 30 for full wave rectification of the alternating current to direct current which is connected to the load terminals 32 and 34 which may be connected to a battery 36 or the like.

The electronic control device G is controlled by an adjustable resistance 38 which is connected across the load in order to be responsive to the voltage conditions at the load. The sliding contact 40 of the adjustable resistance varies the resistance ratios in the resistance 38 to control the amount of D.C. current which is sup-

plied to the control coils 20 of the ferromagnetic devices A and B already described. The electronic control device utilizes a pair of Zener diodes 42 and 44 and a pair of transistors 46 to control this direct current in the control coils 20 in accordance with the variations of the load voltage. The control is energized by being connected to an A.C. source of power in parallel with the primary of the ferromagnetic devices A and B. The alternating current feeds transformer 48, the secondary of which is connected to rectifiers 50 which provide the direct current necessary to operate the electronic control device G. The primary of the transformer may be provided with a signal lamp 52 to indicate to an operator the condition of the electronic control device. The operating characteristics of the electronic control device of the type illustrated are well known in the art, and its characteristics and mode of operation will not be described in further detail.

The coupling diode F, which is connected across the ends of the series-connected control coils 20 is so connected that the D.C. current from the electronic control device G does not flow through it, which will correctly polarize the diode with the control coils, so that a unidirectional pulse of current flows through it from the unsaturated control winding into the saturated control winding. The saturated condition referred to relates to the magnetic core condition of the ferromagnetic devices A and B which alternately become saturated, depending upon the half-cycle relation of the alternating current which flows through their primaries. For example, in FIGURE 1, and again in FIGURES 3 and 5 with the connections as shown and the currents flowing as indicated by the vectors, the ferromagnetic device B becomes saturated, so that a unidirectional pulse of current flows from the control coil 20 in the ferromagnetic device A into the low reactance of the control coil 20 of the ferromagnetic device B which is now saturated. This connection of the diode F with the control coils locks the unsaturated control winding onto the saturated control winding, so that while one core is saturated, the control winding of the other core is short-circuited, in effect, during each half cycle of the frequency of the alternating current supply. In this manner, the impedance of the two control windings in series is effectively reduced to a very small value upon the saturation of either of the two cores of the ferromagnetic devices A and B.

Furthermore, it will be found that when the ferromagnetic devices A and B are coupled by the diode F in the manner indicated, the capacitance discharge current from the resonant capacitor R, which flows in those portions of the primary windings to which the capacitor is connected, will induce its ampere turn counterpart in the control winding connected through the diode F. It is therefore, necessary that the diode F be designed in such a manner as to be capable of conducting appreciable current which usually will have high peak values of short duration. It is also advantageous that the resistance of the diode be designed as low as possible in order that the impedance of the two series connected control windings may be maintained at a very small value.

When the electronic control device G is providing no direct current excitation for the control coils 20, as shown in FIGURE 4, the induced alternating current voltages in the load coils are equal and no current will flow in either of the coupling diodes D and F. However, when the load voltage varies, the electronic control G causes a direct current to flow to the control coils 20, the induced A.C. voltages become unequal and a current flows through the coupling diodes for a considerable portion of each half cycle of the A.C. supply voltage, followed by a short period of inversed voltage across these coupling diodes D and F. Stated in another way, zero amounts of control current in the control coils 20 result in no restraint on the output voltage of the load coils, so that the volt ampere characteristic is the maximum output of the system when uncontrolled. There will, however, be some degree of voltage drop under these circumstances with increased load current in the region from zero load to a point of maximum current output, but beyond this point, the voltage will fall off rapidly as the load is further increased until a short-circuited condition is reached.

The system disclosed has the characteristic that small amounts of D.C. control current in control coils 20 of the ferromagnetic devices A and B will lower the voltage level of the volt-ampere characteristics, including a lowering of the no-load voltage value. The purpose of the control system is not intended to utilize excessive amounts of D.C. control current in the control coils to enable absolute control of output voltage over the whole range from no-load to short-circuit, but is only intended to cover that range of output voltge which is encountered in connection with a load change associated with a given number of battery cells in series. This is a relatively narrow voltage range. The small amount of D.C. current needed for this control of the device is within the range which a single power transistor can provide to energize the control coils 20. However, a pair of power transistors is shown connected in a balanced amplifier circuit which is more than adequate for the purpose, and is primarily used to minimize drifts in voltage, due to changes in ambient temperatures which affect the operation of the transistors themselves. In the usual manner, one Zener diode is used to control the reference voltage, while the second Zener diode may be used to increase the sensitivity of the circuit by utilizing more of the available signal voltage from the variable resistor 38 for control purposes.

In ferromagnetic devices A and B, it has already been pointed out that the conditions illustrated in FIGURE 1, and again in FIGURES 3 and 5, core B will saturate, which, due to the coupling of the load coils in the ferromagnetic devices A and B, by cooperating together through the diode D, the coils of the ferromagnetic device A will drive current through the corresponding interconnected coils of the ferromagnetic device B, traversing the diode D as polarized to allow current to flow from the mid-point 14 to the mid-point 16. This condition obtains for the first half cycle of the induced voltages which is reversed for the next half cycle of the alternating current in which core A will become saturated and the load coils for ferromagnetic device B will drive current through the corresponding coils in the saturated ferromagnetic device A. This is shown in FIGURE 6. It will be noted that the control current in the control coils 20 of both ferromagnetic devices A and B cause the flux to flow in the central core members in a downwardly direction (see FIGURE 1) as is indicated by a vector positioned adjacent the separate control coils 20. The A.C. flux created by the primaries is in opposed relation to the D.C. flux in ferromagnetic device A, while it is in additive relation in the ferromagnetic device B, which indicates that the ferromagnetic device B is saturated, while the ferromagnetic device A is unsaturated under the conditions shown in FIGURE 1. These relations between the D.C. control flux and the A.C. flux created by the primary of the ferromagnetic devices A and B assist the other coupling diode F in driving its current through the respective control coils. During the next half cycle of the alternating current, the situation is similar but with opposite polarities. The currents which flow in the two coupling diodes simultaneously existent are related, depending upon the relation between the number of turns in the various coils and the relation to the resonant primary circuit, in that the ampere turns reach a balanced condition.

The regulating device disclosed, incorporating the invention, controls the 28-volt level of a storage battery within $\pm 1\%$ when the load current varies from zero to rated full load value while the A.C. supply voltage varies as much as $\pm 10\%$.

It is to be understood that the above detailed description of the present invention is intended to disclose an

embodiment thereof to those skilled in the art, but that the invention is not to be construed as limited in its application to the details of construction and arrangement of parts illustrated in the accompanying drawings since the invention is capable of being practiced and carried out in various ways without departing from the spirit of the invention. The language used in the specification relating to the operation and function of the elements of the invention is employed for purposes of description and not of limitation, and it is not intended to limit the scope of the following claims beyond the requirements of the prior art.

What is claimed:

1. In a ferroresonant device for regulating A.C. voltages, a pair of cooperating transformer-like ferromagnetic devices for alternating current each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device each connected in series with a similar coil on the other device and the pairs connected in parallel to provide two parallel load paths, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

2. In a ferroresonant device for regulating A.C. voltages, a pair of identical transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a source of D.C. for the control coils, a pair of load coils for each ferromagnetic device each connected in series with a similar coil on the other device and the pairs connected in parallel to provide two parallel load paths, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

3. In a ferroresonant device for regulating A.C. voltages, a pair of identical transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device each connected in series with a similar coil on the other device and the pairs connected in parallel to provide two parallel load paths, a source of D.C. for the control coils responsive to the voltage of the load coils, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

4. In a ferroresonant device for regulating A.C. voltages, a pair of similar transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device each connected in series with a similar coil on the other device and the pairs connected in parallel to provide two parallel load paths, an electronic control device responsive to the voltage of the load coils to create a source of D.C. for the control coils, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

5. In a ferroresonant device for regulating A.C. voltages, a pair of similar transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with each other in voltage additive relation and with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device vice each connected in series with an identical coil on the other device in voltage additive relation and the pairs connected in parallel to provide two parallel load paths, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

6. In a ferroresonant device for regulating A.C. voltages, a pair of similar transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with each other in voltage additive relation and with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device each connected in series with an identical coil on the other device in voltage additive relation and the pairs connected in parallel to provide two parallel load paths, an electronic control device responsive to the voltage of the load coils to create a source of D.C. for the control coils, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

7. In a ferroresonant device for regulating A.C. voltages, a pair of identical transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with each other in voltage additive relation and with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a pair of load coils for each ferromagnetic device vice each connected in series with an identical coil on the other device in voltage additive relation and the pairs connected in parallel to provide two parallel load paths, a source of D.C. for the control coils varied by the voltage of the load coils, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

8. In a ferroresonant device for regulating A.C. voltages, a pair of similar transformer-like ferromagnetic devices for alternating current cooperating together each

including series-connected energizing primary coils, a pair of coils one for each ferromagnetic device in series connection with each other in voltage additive relation and with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a source of D.C. for the control coils, a pair of load coils for each ferromagnetic device each connected in series with an identical coil on the other device in voltage additive relation and the pairs connected in parallel to provide two parallel load paths, an electronic means to control the D.C. for the control coils in accordance with the voltage of the load coils, and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

9. In a ferroresonant device for regulating A.C. voltages, a pair of identical transformer-like ferromagnetic devices for alternating current cooperating together each including series-connected energizing primary coils, a pair

of coils one for each ferromagnetic device in series connection with each other in voltage additive relation and with a capacitor and in extended series connection with the primary coils to form a resonating circuit in cooperative relation with the primary coils, a D.C. control coil for each ferromagnetic device whose flux in one device is additive to the A.C. flux of the primary and opposed in the other, a source of D.C. consisting of rectified A.C. from said primary source, a pair of load coils for each ferromagnetic device each connected in series with an identical coil on the other device in voltage additive relation and the pairs connected in parallel to provide two parallel load paths, an electronic means energized from said D.C. source to create a D.C. source for the control coils varied in accordance with the voltage of the load coils and a pair of diodes, one connected across the ends of the control coils in opposed polarity to the D.C. current, and the other connected to the center points of the parallel connected load coils.

No references cited.