

July 7, 1942.

B. D. BEDFORD

2,289,090

ELECTRIC CIRCUIT

Filed Feb. 3, 1941

2 Sheets-Sheet 1

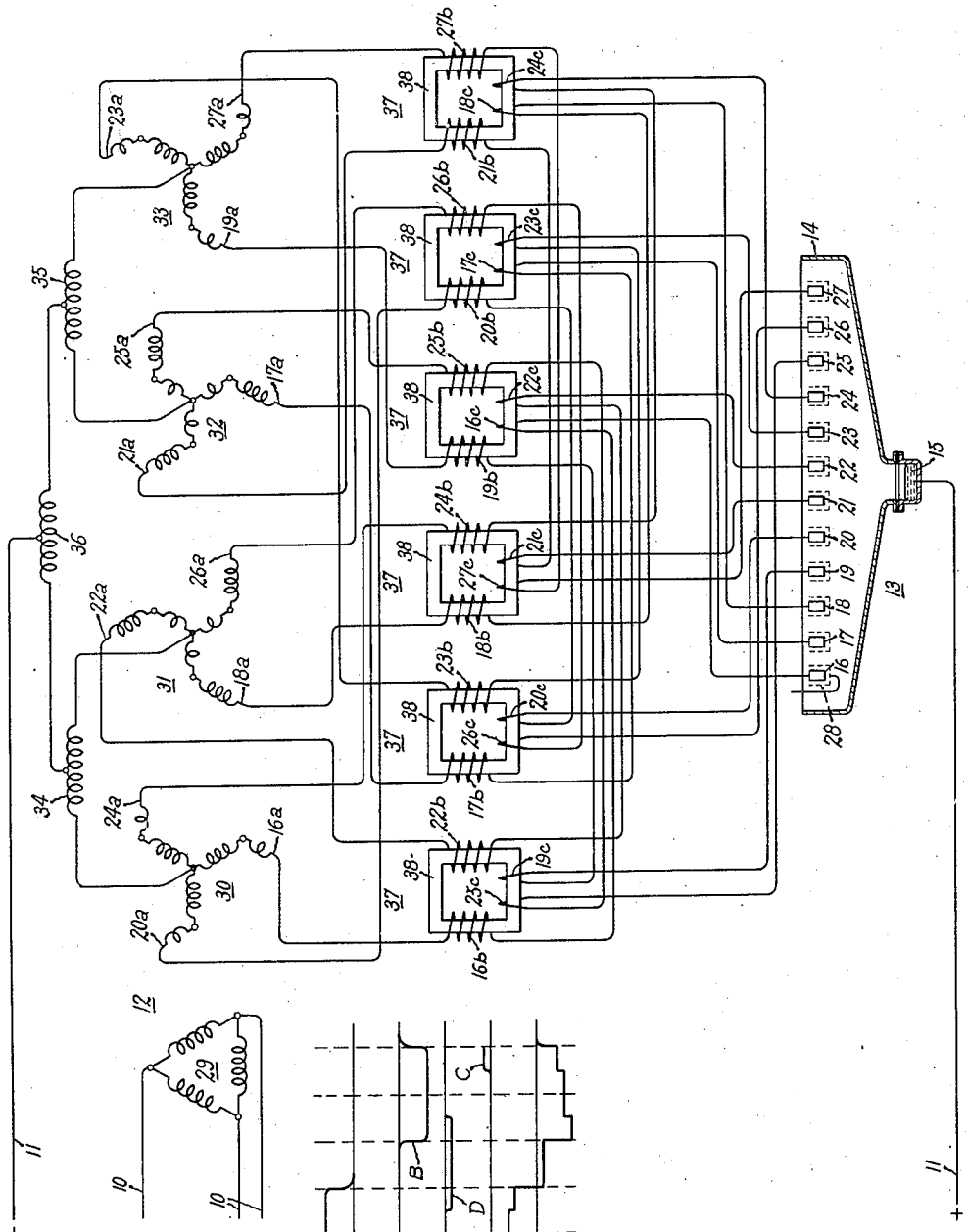


Fig. 1.

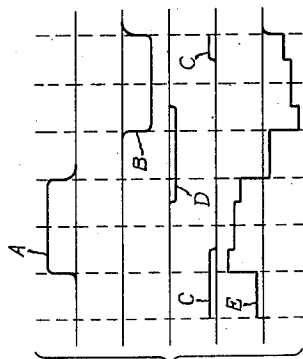


Fig. 2.

Inventor:
Burnice D. Bedford
by *Harry E. Surham*
His Attorney.

July 7, 1942.

B. D. BEDFORD

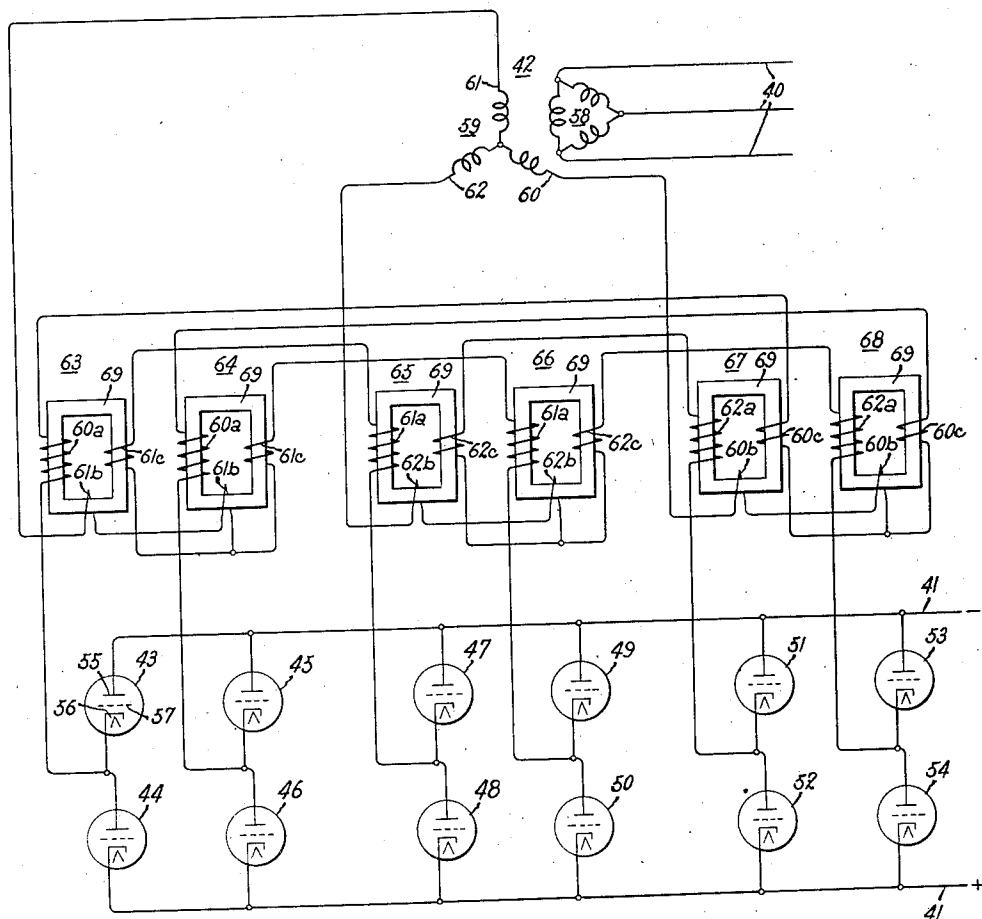
2,289,090

ELECTRIC CIRCUIT

Filed Feb. 3, 1941

2 Sheets-Sheet 2

Fig. 3.



Inventor:
Burnice D. Bedford,
by *Harry E. Drunkau*
His Attorney.

UNITED STATES PATENT OFFICE

2,289,090

ELECTRIC CIRCUIT

Burnice D. Bedford, Schenectady, N. Y., assignor
to General Electric Company, a corporation of
New York

Application February 3, 1941, Serial No. 377,142

10 Claims. (Cl. 175—363)

My invention relates to electric circuits and more particularly to electric valve circuits including a plurality of electric discharge paths operating in parallel.

In electric valve circuits including electric valve means of the type using ionizable mediums such as gas or vapor, there has been evidenced a decided need for apparatus to eliminate or reduce to a minimum the arc-back conditions to which these electric valves may be subjected in operation. In my Patent 2,126,603, dated August 9, 1938, and assigned to the same assignee as the present invention, an electric valve system is disclosed in which saturable reactors are employed in each of the anode leads of the valve circuit. Each of the reactors is arranged to saturate at a comparatively low value of current and when it becomes unsaturated during the reduction of current at the end of the conducting period of the discharge path with which it is associated, the increase in impedance causes the anode current to decrease very gradually and approach the zero axis substantially tangentially. This reduction in the rate of decrease of current decreases the voltage gradient between the main electrodes of the electric valves and causes a reduction in the number of arc-backs. In order to eliminate the effect of the inductive impedance to the initiation of discharge in the electric valves, a control winding on each of the saturable reactors is provided which conducts the current of another phase of the system and has a time phase relation such that the core of the reactor is saturated at the time that the anode with which it is associated starts to conduct current. In this manner there is substantially no impedance offered by the saturable reactors to the initiation of current in the discharge paths. In electric circuits employing a plurality of electric discharge paths in parallel or a plurality of parallel paths through mechanical switching means there is a tendency for there to be an unbalance between the currents of the parallel paths. This tendency for the parallel paths to conduct unequal currents may be reduced by ordinary reactors. Ordinary reactors, however, are wasteful of energy and delay the build-up of current at the beginning of each period of conduction, resulting in poor power factor on the alternating current side of the electric translating apparatus. By utilizing saturable reactors of the type employed in the above-mentioned patent and properly connecting the control windings with respect to the groups of par-

allel discharge paths it is possible to obtain an arrangement which not only reduces the tendency of the electric valves to arc back, but also tends to force a current balance between the parallel operating electric valves without a substantial waste of electrical energy. Such an arrangement is particularly desirable in electric valve installations where grid control is not employed.

It is an object of my invention to provide a new and improved electric valve circuit.

It is another object of my invention to provide new and improved electric translating apparatus including a plurality of parallel current paths in which a predetermined division of load current between the parallel paths is insured.

It is still another object of my invention to provide a new and improved electric valve circuit, including a plurality of electric discharge paths in parallel, the operation of which is characterized by an equal distribution of load current between the parallel discharge paths and an absence of arc-backs.

In accordance with an illustrated embodiment of my invention I provide an electric valve circuit employing electric valves, preferably of the ionizable medium type, for controlling the transfer of energy between an alternating current circuit and a direct current circuit. A phase multiplying transformer including a plurality of groups of phase windings is employed and saturable inductive devices, each including impedance windings connected in circuit with the electric discharge valves associated with each of the phase windings. The inductive devices are provided with control windings which carry the current conducted by electric valves associated with groups of phase windings differing from those with which the impedance windings of that device are associated. The time phase relation of the current conducted by the impedance windings and the control windings of each reactor or inductive device is such that the reactor core is variably saturated at the beginning of the conductive period in accordance with the current conducted by the control windings, but is unsaturated at the end of the conductive period so that the impedance winding of the reactor offers an increased impedance as the current approaches zero and in this way the rate of decrease of the current through each valve during this period is kept at a low value. In order that the pre-saturation of the core by the control windings will tend to maintain a current balance between

the current conducted by the electric valves associated with each of the groups of phase windings, the control winding associated with the impedance windings connected in the anode leads of the valves associated with one group of phase windings are energized by the current conducted by the electric valves associated with other groups of phase windings.

In accordance with another illustrated embodiment of my invention, a plurality of parallel electric discharge paths are associated with each phase winding of an inductive network. In this arrangement the current conducted by one of the parallel discharge paths variably saturates the core associated with the corresponding discharge path associated with the phase which is to become conductive at the next succeeding interval. In this way any decrease in the current conducted by one of the parallel discharge paths associated with one of the phase windings causes an increase in the presaturation of the core structure of the reactor associated with the corresponding discharge path associated with the phase which becomes conductive at the next interval so that an equalization of the load current conducted by each of the parallel discharge valves is maintained by variations in the magnitude of the inductive impedance in series therewith.

For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims. In the drawings, Fig. 1 is a schematic representation of one embodiment of my invention, Fig. 2 represents certain operating characteristics of the circuit shown in Fig. 1, and Fig. 3 is a schematic representation of a modification of my invention.

Referring now to Fig. 1 of the accompanying drawings, my invention is diagrammatically shown as applied to an electric valve circuit for transmitting energy between an alternating current circuit 10 and a direct current circuit 11 through a transformer 12 and electric valve means 13, preferably of the type employing an ionizable medium such as a gas or vapor. As illustrated, the electric valve means comprises a container 14 having a single pool type cathode 15 of conducting liquid, such as mercury, and in the particular embodiment illustrated, twelve anodes designated by numerals 16-27. A control member 28 may be associated with each of the anodes for controlling the conductivities of the discharge paths formed by the anodes 16-27 and cathode 15. The control members may be energized by any suitable excitation circuit (not shown) if desired.

The transformer 12 comprises a delta connected primary winding 29 and a quadruple-Y secondary connection including four groups of zigzagged Y inductive networks 30, 31, 32 and 33. The neutral terminals of the Y connected networks 30 and 31 are interconnected by an interphase transformer or phase equalizing inductive impedance element 34, while the inductive networks 32 and 33 have their neutral terminals interconnected by a similar interphase transformer 35. The midterminals of interphase transformers 34 and 35 are interconnected by an interphase transformer 36, the midterminal of which is connected to one of the lines of the direct current circuit 11. The other line of the direct current circuit is connected with the cathode 16 of the electric discharge means 13.

As is well understood, the quadruple-Y connec-

tion just described is effective to produce twelve-phase secondary voltages at the twelve end terminals of the four inductive networks 30-33 which make up the secondary windings of the transformer 12. For facility in explanation, the end terminals have been numbered with the same numbers as the anodes with which they are connected but with a suffix *a*. Thus the twelve end terminals of the networks 30-33, inclusive, have been numbered 16*a* to 27*a* corresponding to the anodes 16-27 with which they are connected.

In order to control the rate of change of current through the electric discharge paths to maintain a distribution of current and to minimize the voltage gradient across the discharge paths at the end of each period of conduction, the saturable inductive impedance devices 37 are provided. Each of the impedance devices includes a core member 38 having a pair of impedance windings associated therewith and each of which is connected in circuit with one of the anodes of the electric discharge device 13. For the sake of clarity these windings have been numbered with the same number as the anode with which they are connected but with a suffix *b*. Thus the impedance winding interconnecting terminal 16*a* with anode 16 is designated 16*b*. Similarly, the other impedance windings of the inductive devices 37 are numbered 17*b* to 27*b*, inclusive, corresponding to the anodes 17 to 27 with which they are connected. It will be noted that the two impedance windings such as 16*b* and 22*b* associated with one of the saturable inductive devices 37, are associated with anodes 16 and 22, respectively, which are energized to conduct current at intervals displaced substantially 180 electrical degrees. Wound on the core member 38 of each of the devices 37 is also a pair of control windings of relatively few turns compared with the impedance windings 16*b* and 22*b*. Each of the control windings is connected in circuit with an anode energized by a phase winding of a different network from the networks with which the impedance windings 16*b* and 22*b* are associated. Each of the control windings is designated with the number of the anode with which it is in series but with a suffix *c*. Thus, the control winding of the device 37 with which the main windings 16*b* and 22*b* are associated are energized by the current conducted by the anodes 19 and 25 and are designated by numerals 19*c* and 25*c*, respectively. The current conducted by the control windings 19*c* and 25*c* produces flux in opposite directions in the magnetic core 38 at electrically displaced intervals.

As is well understood by those skilled in the art, the electric valve system thus far described may be operated to interchange energy between the alternating current circuit 10 and the direct current circuit 11. The quadruple-Y secondary networks, including the interphase transformers 34, 35 and 36, are effective to produce twelve-phase voltages which, when impressed on the anodes 16 to 28, cause four anodes to conduct simultaneously with each anode conducting for a period of 120 electrical degrees. Although the system may be operated with any desired form of grid control for voltage regulation or other purposes, none has been illustrated since the present invention is equally applicable to systems employing any of the well known types of grid control or operating simply as a rectifier without grid control.

The operation of the saturable inductive de-

vices 37 to produce a load balance and a minimum voltage gradient across the discharge paths at the end of each period of conduction will be understood more readily from an examination of Fig. 2 which illustrates the magnetomotive forces produced in one of the core structures 38 by the windings associated therewith.

Referring now to Fig. 2, the upper curve A represents the magnetomotive force produced in the core structure by the winding 16b. Similarly, the curve B represents the magnetomotive force impressed on the core structure by the winding 22b. The periods of conduction are 120 degrees and the time of conduction of the anode 22, in series with which the winding 22b is connected, is displaced 180 degrees with respect to the period of conduction of the anode 16 in series with which the winding 16b is connected. The control winding 25c, associated with terminal 25a and anode 25, produces the magnetomotive force illustrated by the curve C which occurs at a time to presaturate the core 38 at the beginning of the period of conduction of the anode 16. This magnetomotive force is in the same direction as the magnetomotive force produced by the current flowing in the winding 16b. In this way the impedance of the winding 16b is decreased to a fairly low value dependent on the current conducted by control winding C at the start of the period of conduction of anode 16 so that the initiation of current in the associated discharge path is not delayed. It is to be noted that the control winding 25c is associated with the terminal 25a of the inductive network 32 which is different from the network 30 with which the winding 16b is associated and the magnitude of the current conducted by a discharge path associated with the network 32 controls the amount of presaturation of the core structure 38 with which winding 16b is associated. In this way the magnitude of the impedance offered to the build-up of current through the discharge path 16 is controlled in accordance with the current conducted by one of the parallel operating discharge paths associated with a different network. In this manner the saturable inductive devices tend to produce a load balance since an increase in current conducted by an anode associated with one network tends to decrease the impedance in circuit with an anode which is to conduct at a succeeding interval of time and associated with another network. Similarly, a decrease in current conducted by an anode associated with one network presaturates the core associated with an impedance winding connected in series with an anode energized from another network to a lesser extent and tends to decrease the current conducted by the latter anode. The control winding 19c is wound to produce a magnetomotive force in the same direction as the winding 22b associated with anode 22 and has the proper time relation to presaturate the core 38 at the beginning of the period of conduction of the anode 22 in the same manner as the control winding 25c controls the impedance of winding 16b. The magnetomotive force produced by winding 19c is illustrated by the curve D of Fig. 2. From the foregoing it is seen that the core structure with which the impedance winding connected with each anode is associated; is presaturated a variable amount at the beginning of the period of conduction of each of the anodes to force a load balance. From an inspection of Fig. 2 it is also apparent that the magnetomotive forces produced by the control windings 25a and 19a overlap the periods of conduction of the

anodes 16 and 22 in such a manner that during the latter part of the period of conduction of the anodes 16 and 25 the magnetomotive forces produced by the control windings oppose the magnetomotive forces produced by the impedance windings 16b and 22b. In this manner, the magnetomotive force impressed on the core structure 38 reaches zero before the current through the impedance windings 16b and 22b reaches zero and accordingly the impedance of the windings 16b and 22b increases at the end of each period of conduction to decrease the rate of current change. The resultant magnetomotive force impressed on the core structure 38 is illustrated in the bottom curve E of Fig. 2.

From the foregoing it is seen that the present invention provides a system of saturable anode reactors with control windings which makes very good use of the magnetic material of the reactors and at the same time tends to limit arc backs and to force a load balance without utilizing a large amount of energy of the supply circuit. The invention, although not limited thereto, is particularly well adapted for use with electric valve circuits supplying a load which does not vary over a wide range.

In Fig. 3 I have shown a modified form of my invention embodied in a circuit in which a plurality of parallel electric discharge paths are associated with each phase winding of the secondary network of a supply transformer and in which electric discharge paths are connected for full wave operation.

Referring now to Fig. 3, a three-phase alternating current supply circuit 40 and a direct current load circuit 41 are interconnected by electric translating apparatus comprising a transformer 42 and a plurality of electric valves 43-54, inclusive. The electric valves are preferably of the type containing an ionizable medium, such as a gas or vapor, and each includes an anode 55, a cathode 56 and a control member or grid 57. The transformer 42 comprises a delta-connected primary winding 58 and a Y-connected secondary winding 59 having three phase terminals 60, 61 and 62. The electric valves 43 and 45 are connected in parallel to be energized from the phase terminal 61 and to conduct current when the phase terminal 61 is negative. The electric valves 44 and 46 are connected in parallel to be energized from the phase terminal 61 and to conduct current when the terminal 61 is positive. That is, the valves 43-46 form a full wave rectifier having two parallel paths conducting for each half cycle. Similarly, the valves 47-50 are associated with the phase terminal 61 and the valves 51-54 are associated with the phase terminal 62.

In order to maintain a division of load current between the parallel operating electric valves, such as 44 and 46 for example, I provide a plurality of saturable inductive impedance devices or reactors 63-68, inclusive, each of which includes a core structure 69. Associated with each of the core structures is an impedance winding connected in series between one of the phase terminals and the common terminal of a pair of electric valves connected for full wave operation. Thus, the impedance winding 60a of the saturable inductive device 63 is connected in series with the phase terminal 60 and the common terminal of the electric valves 43 and 44. Control windings 61b and 61c are also associated with core structure 69 of reactor 63. Similarly, the reactor 64 includes an impedance winding 60d con-

nected in series with the phase terminal 60 and the common terminal of the electric valves 45 and 46, a pair of control windings 61b and 61c. In like manner, the reactors 65 and 66 include the impedance windings 61a and control windings 62b and 62c while the reactors 67 and 68 include the impedance windings 62a and control windings 60b and 60c. The manner in which the impedance windings and control windings of the reactors are connected between the phase terminals of the transformer secondary 59 and the common terminals of the electric valves 43 to 54 may best be explained by tracing the circuits of the windings of reactors 63 and 64. The circuit of the impedance winding 60a of reactor 63 may be traced from the phase terminal 60 through the control windings 60b of reactors 67 and 68, control winding 60c of reactor 67, impedance winding 60a of reactor 63 to the common terminal of electric valves 43 and 44. Similarly, the circuit of impedance winding 60a of reactor 64 may be traced from the phase terminal 60 through the control windings 60b of reactors 67 and 68, control winding 60c of reactor 68, the impedance winding 60a of reactor 64 to the common terminal of electric valves 45 and 46. Thus it is seen that the total current conducted by the phase terminal 60 flows through the control winding 60b of reactors 67 and 68, and then divides with part flowing through the control winding 60c of reactor 67 and the impedance winding 60a of reactor 63 and the remainder flowing through the control winding 60c of reactor 68, the impedance winding 60a of reactor 64 to the common terminal of electric valves 45 and 46. Similarly, the circuit of control windings 61b and 61c of reactors 63 and 64 may be traced from the phase terminal 61 through the control windings 61b in series and thence through control winding 61c of reactor 63, the impedance winding 61a of reactor 65 to the common terminal of electric valves 47 and 48. The circuit for control winding 61c of reactor 64 is completed from the winding 61b of reactor 64 through the winding 61a of reactor 66 to the common terminal of electric valves 49 and 50. Thus it is seen that the current conducted by the electric valves 47 to 50 inclusive determines the currents conducted by the control windings 61b and 61c of reactors 63 and 64 and in this way control the impedance of the windings 60a of reactors 63 and 64 to control the magnitude of the current conducted by valves 43 to 46 inclusive. The number of turns in the control windings 60c, 61c and 62c bear the same relation to the number of turns of the windings 60b, 61b and 62b as the number of parallel paths associated with each of the phase windings 60, 61 and 62 and in the particular embodiment illustrated have a turn ratio of 2 to 1. From the foregoing description it is seen that the winding 61b of reactor 63 conducts the same current as the electric valves 47 and 48 and the winding 61b of reactor 64 conducts the same current as the electric valves 49 and 50, while windings 61c of reactors 63 and 64 conduct the total current of valves 47 to 50 inclusive. The control windings 61b are connected to produce a magnetomotive force in the same direction as the impedance winding 60a when valves 44 and 46 and 47 and 49 are conducting while the control windings 61c are wound in a direction to produce a magnetomotive force opposing the magnetomotive forces of windings 60a and 61b of reactors 63 and 64. Thus it is seen that if valves 47 and 49 conduct currents of equal

magnitude the net ampere turns produced by the control windings 61b and 61c are zero and the saturation of the core members 69 of reactors 63 and 64 is determined simply by the current conducted by the windings 60a. If, however, one of the parallel valves associated with the terminal 61 conducts more than its share of the current the magnetomotive force produced by control windings 61b and 61c of reactors 63 and 64 will be unequal. For example, if valve 47 conducts more current than valve 49 the magnetomotive force produced by control winding 61c of reactor 63 will be greater than the magnetomotive force produced by the winding 61b of reactor 63 and the net result will be a magnetomotive force in the core structure 69 at the beginning of the conducting period of the valves associated with the main terminal 60 which opposes the magnetomotive force produced by current which would flow in the winding 60a when the valve 44, associated therewith, conducts. This will increase the effective impedance of winding 60a and reduce the current conducted by the valve 44 with respect to the total current conducted by the valves 44 and 46. Similarly, under the conditions just described where electric valve 47 tends to carry less current than valve 49, for example, the control windings 61b and 61c of reactor 64 will produce a magnetomotive force in the core structure which is in the same direction as the magnetomotive force produced by the winding 60a. This will decrease the effective impedance of the winding 60a of reactor 64 at the beginning of the period of conduction of the electric valve 46 associated therewith so that the current conducted by the valve 46 will be increased, and in this way any tendency for any one of the parallel electric discharge valves associated with successive phase windings to progressively conduct larger and larger proportions of the total current is reduced to a minimum.

The foregoing description has been limited to the action of reactors 63 and 64 together with the control windings associated with the phase terminal 61 for controlling the saturation of the core structures associated therewith for the period when valves 44 and 46 and 47 and 49 are conducting. The operation of reactors 63 and 64 is similar for the interval when valves 43 and 45 and 48 and 50 are conducting. In a similar way, the electric valves 47-50 which are energized from the phase terminal 61 include the impedance windings 61a which are connected in series with the phase terminal 61, the control windings 61b and 61c associated with reactors 63 and 64 and the common terminals of the valves 47, 48 and 49, 50, respectively. Control windings 62b and 62c connected in circuit with electric valves 51-52 and 53-54 and associated with the core structures of the reactors 65 and 66 control the saturation thereof in a manner similar to that described in connection with reactors 63 and 64. Similarly, the reactors 67 and 68 are controlled in accordance with the current conducted by the valves 43 to 46 inclusive by control windings 60b and 60c.

It is believed that the operation of the embodiment of my invention illustrated in Fig. 3 will be apparent from the foregoing detailed description. Although the phase rotation of the network 59 has been assumed to be 60, 61, 62, it will be noted that the control windings of the reactors associated with the phase 60 are energized by the current conducted by the electric valve associated with the phase 61 which is

the succeeding phase rather than the preceding phase. However, in the full wave operation the succeeding phase, as far as positive half waves are concerned, conducts current at a proper time to control the presaturation of the windings of the preceding phase when the valves associated therewith which conduct current during the negative half waves of the supply terminal. Thus, for example, the current conducted by valves 47 and 49 controls the saturation for the reactors 63 and 64 at the beginning of the conducting periods of valves 44 and 46. This arrangement is an advantage since the control magnetomotive force overlaps the period of conduction of the valves which it controls.

While I have shown and described particular embodiments of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention, and I therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. In combination, a supply circuit, a load circuit, at least one of said circuits being an alternating current circuit, electric translating apparatus interconnecting said circuits and including a plurality of parallel electric circuits, circuit controlling means for rendering each of said parallel circuits unilaterally conductive at electrically displaced intervals for periods of less than 180 electrical degrees, means for controlling the flow of current through said parallel electric circuits including an impedance winding and a control winding in series in each of said parallel electric circuits, a plurality of saturable core structures each having two of said impedance windings and two of said control windings associated therewith, the windings associated with each core structure being connected in a different one of said parallel electric circuits so that the periodic unidirectional magnetomotive forces produced by each of the control windings overlap the periodic unidirectional magnetomotive forces produced by both impedance windings, said windings being wound on said core structure in such a manner that the magnetomotive force produced by one of said control windings is in the same direction as the magnetomotive force produced by one of said impedance windings at the beginning of the period of conduction of the parallel electric circuit with which the impedance winding is associated and opposes the magnetomotive force produced by the other of said impedance windings during the latter portion of the conducting period of the parallel electric circuit with which said other impedance winding is associated.

2. In combination, a supply circuit, a load circuit, at least one of said circuits being an alternating current circuit, electric translating apparatus interconnecting said circuits including a plurality of parallel electric circuits, circuit controlling means for rendering each of said parallel circuits conductive and non-conductive for predetermined intervals, each of said parallel electric circuits including an impedance winding and a control winding in series, a plurality of core structures each having two of said impedance windings and two of said control windings associated therewith, the impedance windings associated with each of said core structures being connected in series with certain of

said parallel electric circuits which conduct current at intervals displaced 180 electrical degrees, said impedance windings being wound to produce unidirectional magnetomotive forces in said core structure in opposite directions, the control windings associated with each core structure being wound to produce unidirectional magnetomotive forces in opposite directions and each being connected in certain of said parallel electric circuits which conduct current at intervals which overlap portions of the periods of conduction of both of the parallel circuits with which the impedance windings are associated.

3. In combination, an alternating current supply circuit, a direct current load circuit, electric translating apparatus interconnecting said circuits including a plurality of electrically displaced polyphase inductive networks and a plurality of electric discharge paths associated therewith, said inductive networks being arranged in two groups, a saturable inductive device comprising a core structure, an impedance winding associated with said core structure and connected in series with an electric discharge path associated with an inductive network of one group, a second impedance winding associated with said core structure and connected in series with an electric discharge path of another inductive network of the same group, said impedance windings being wound on said core structure in a direction to produce opposing magnetomotive forces in said core structure when the electric discharge paths with which they are associated conduct current in the normal direction, a pair of control windings associated with said core structure and each connected in series with an electric discharge path associated with a different inductive network of the other of said groups, the current conducted by said control windings being electrically displaced with respect to the current conducted by said impedance windings to produce substantial saturation of said core structure at the beginning of the conducting period of the electric discharge paths associated with each of said impedance windings to vary the impedance thereof in accordance with the current conducted by said control windings and to oppose the magnetomotive force produced by said impedance windings at the end of each conducting period so that the impedance of the impedance windings is substantially increased at the end of each period of conduction.

4. In combination, a supply circuit, a load circuit, at least one of said circuits being an alternating current circuit, electric translating apparatus interconnecting said circuits including a plurality of electrically displaced polyphase inductive networks and a plurality of electric discharge paths associated therewith, means for controlling the flow of current through said electric discharge paths to maintain a predetermined division of load current between the discharge paths associated with different inductive networks comprising a plurality of saturable reactors each including a core structure, an impedance winding and a control winding, said impedance winding being connected in series with an electric discharge path associated with one of said networks and said control winding being energized in accordance with the current conducted by an electric discharge path associated with another of said networks to produce a unidirectional magnetomotive force in said core structure in the same direction and in overlap-

ping relation with the first portion of the magnetomotive force produced by current conducted by the electric discharge path with which said impedance winding is associated to saturate variably said core structure in accordance with the current conducted by the electric discharge path with which said control winding is associated.

5. In combination, an alternating current circuit, a direct current circuit, electric translating apparatus interconnecting said circuits including a plurality of parallel groups of electric discharge paths energized to conduct current at electrically displaced intervals with at least one path in each group conducting simultaneously, means for controlling the rate of change of current through each of said discharge paths comprising saturable reactance means including a core structure, an impedance winding connected in series with one discharge path, a control winding energized in accordance with the current conducted by a discharge path of a different group from the one with which the impedance winding associated with the same core structure is associated for producing a unidirectional magnetomotive force to presaturate variably said core structure and thereby control the rate of change of current through the discharge path with which the impedance winding is associated at the beginning of the period of conduction thereof and so displaced electrically with respect to the period of conduction of said last mentioned discharge path that the impedance of the winding in series therewith is effective to decrease the rate of change in current at the end of the period of conduction.

6. In combination, a polyphase alternating current circuit, a direct current circuit, electric translating apparatus interposed between said circuits including a plurality of groups of parallel connected electric valve means and a plurality of saturable reactors each including a core member, an impedance winding connected in series relation with a predetermined different one of said electric valve means for controlling the flow of current therethrough and a control winding energized in accordance with the current conducted by other of said parallel electric valve means energized to conduct current at a time interval displaced with respect to the period of conduction of the electric valve means associated with said impedance winding for impressing a periodic magnetomotive force on said core structure to vary the saturation thereof at the beginning of the conducting period of the electric valve means connected in series with said impedance winding in accordance with the current conducted by said other parallel electric valve means.

7. In combination, a supply circuit, a load circuit, at least one of said circuits being an alternating current circuit, electric translating apparatus interconnecting said circuits and including a plurality of electrically displaced groups of parallel electric circuits, circuit controlling means for rendering each of said parallel electric circuits conductive and nonconductive for predetermined intervals, means for controlling the flow of current through each of said parallel electric circuits to maintain a predetermined division of load current therebetween comprising an impedance winding and a control winding connected in series with each of said parallel electric circuits, a plurality of saturable core structures, one of said impedance windings and

one of said control windings being associated with each of said core structures, the windings associated with each core structure being connected in parallel circuits of a different group so that the current conducted by said control winding is effective to saturate variably the core structure at the beginning of the period of conduction of the electric circuit with which the impedance winding is associated in accordance with the current conducted by a parallel electric circuit of another group.

8. In combination, an alternating current circuit, a direct current circuit, electric translating apparatus interconnecting said circuits including a plurality of groups of parallel electric circuits, circuit controlling means for rendering each of said groups of circuits unilaterally conductive at electrically displaced intervals for a predetermined period, means for controlling the flow of current through said parallel electric circuits of each group to maintain a predetermined division of load current therebetween including a plurality of saturable inductive devices each comprising a core structure, an impedance winding connected in series with one of said discharge paths, and means for variably saturating said core structure at the beginning of the period of conduction of the parallel electric circuit with which the impedance winding associated therewith is in series in accordance with deviations from the desired division of load current between the parallel electric circuits of another group which conducts at a preceding interval of time.

9. In combination, an alternating current circuit, a direct current circuit, electric translating apparatus interconnecting said circuits and including a plurality of groups of parallel electric circuits, circuit controlling means for rendering each of said groups of parallel circuits unilaterally conductive at electrically displaced intervals, means for controlling the rate of change of current through said parallel electric circuits to maintain a predetermined division of load current therebetween including an impedance winding in series with each of said circuits and an associated saturable core structure, a plurality of control windings associated with each core structure for producing a net magnetomotive force in said core structure which varies in accordance with the division of load current between the parallel electric circuits which conduct at the next preceding interval of time to vary the impedance of said impedance windings in a direction to maintain the desired division of load current therebetween.

10. In combination, an alternating current circuit, a direct current circuit, electric translating apparatus interconnecting said circuits and including a plurality of groups of parallel electric circuits, circuit controlling means for rendering each of said groups of parallel circuits conductive at electrically displaced intervals, means for controlling the flow of current in the groups of parallel electric circuits including a plurality of saturable inductive impedance devices each including a saturable core structure, an impedance winding connected in one parallel circuit of one group and a pair of control windings connected in circuit with another group of parallel circuits, one of said control windings conducting the full current of said other group and wound in a direction to produce a magnetomotive force in the same direction as the current conducted by said im-

pedance winding at the beginning of the conducting interval of the circuit in which it is connected and the other of said control windings conducting the current conducted by one of the parallel circuits of said other group and wound in a direction to oppose the magnetomotive force produced by said first mentioned control winding, the turn ratio of said second mentioned control

winding and said first mentioned control winding being the same as the number of parallel electric circuits of each of said groups so that substantially no magnetomotive force is produced by said control winding when the current is equally divided between said parallel electric circuits of each group.

BURNICE D. BEDFORD.