April 21, 1936. H. WINOGRAD 2,038,505

RECTIFIER CONTROL SYSTEM

Filed Aug. 7, 1933 3 Sheets-Sheet 1

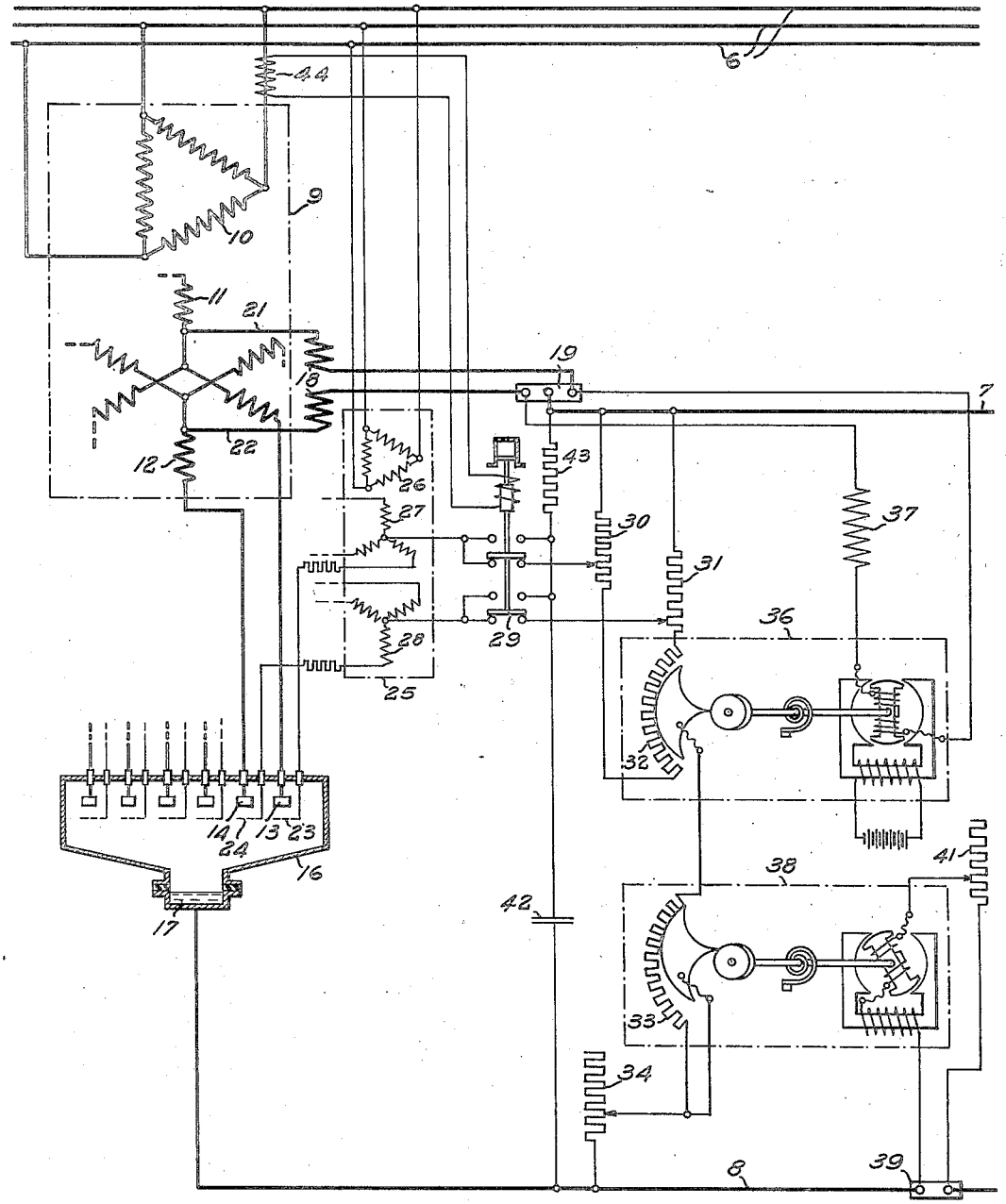


Fig. 1

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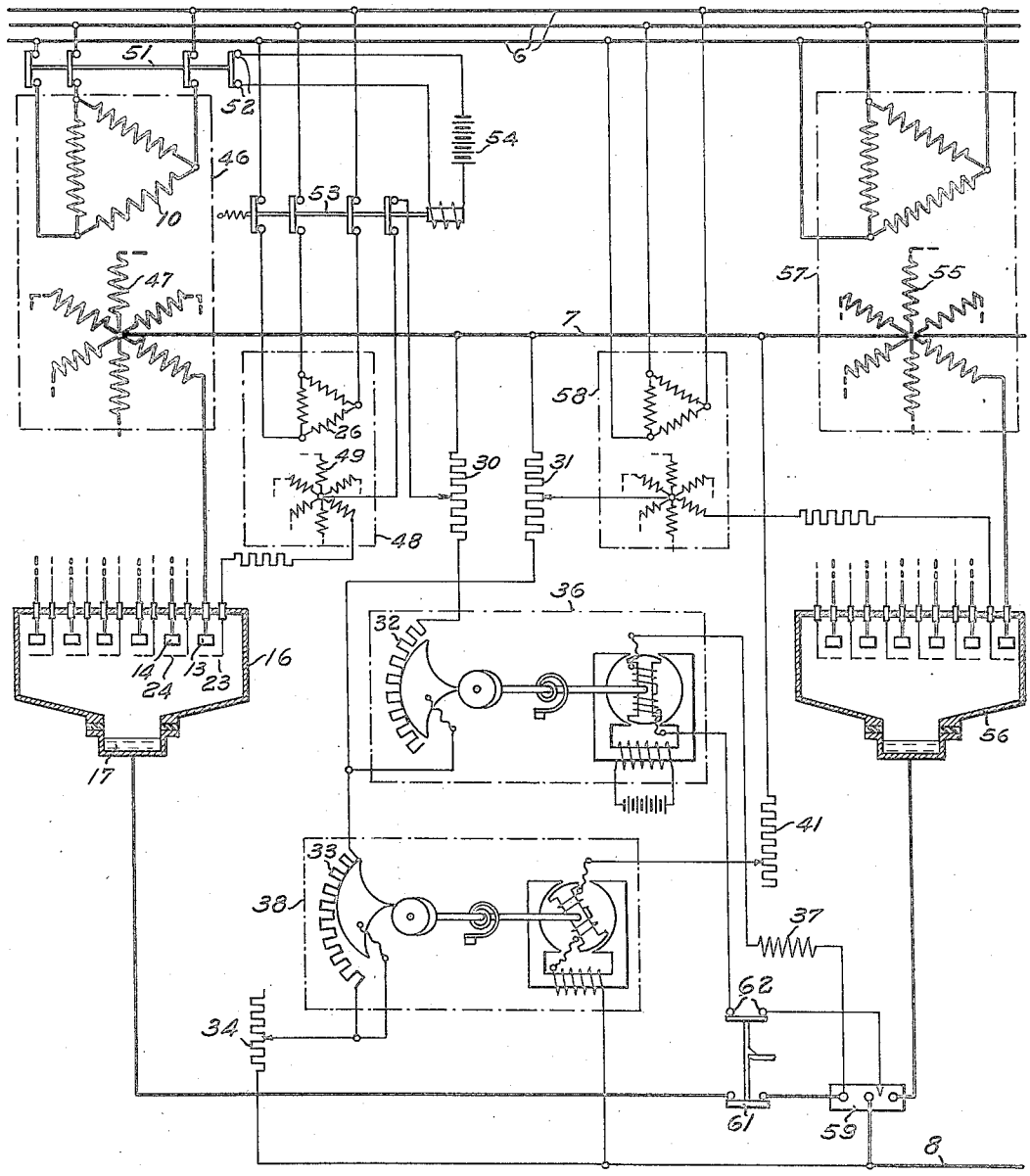


Fig. 2

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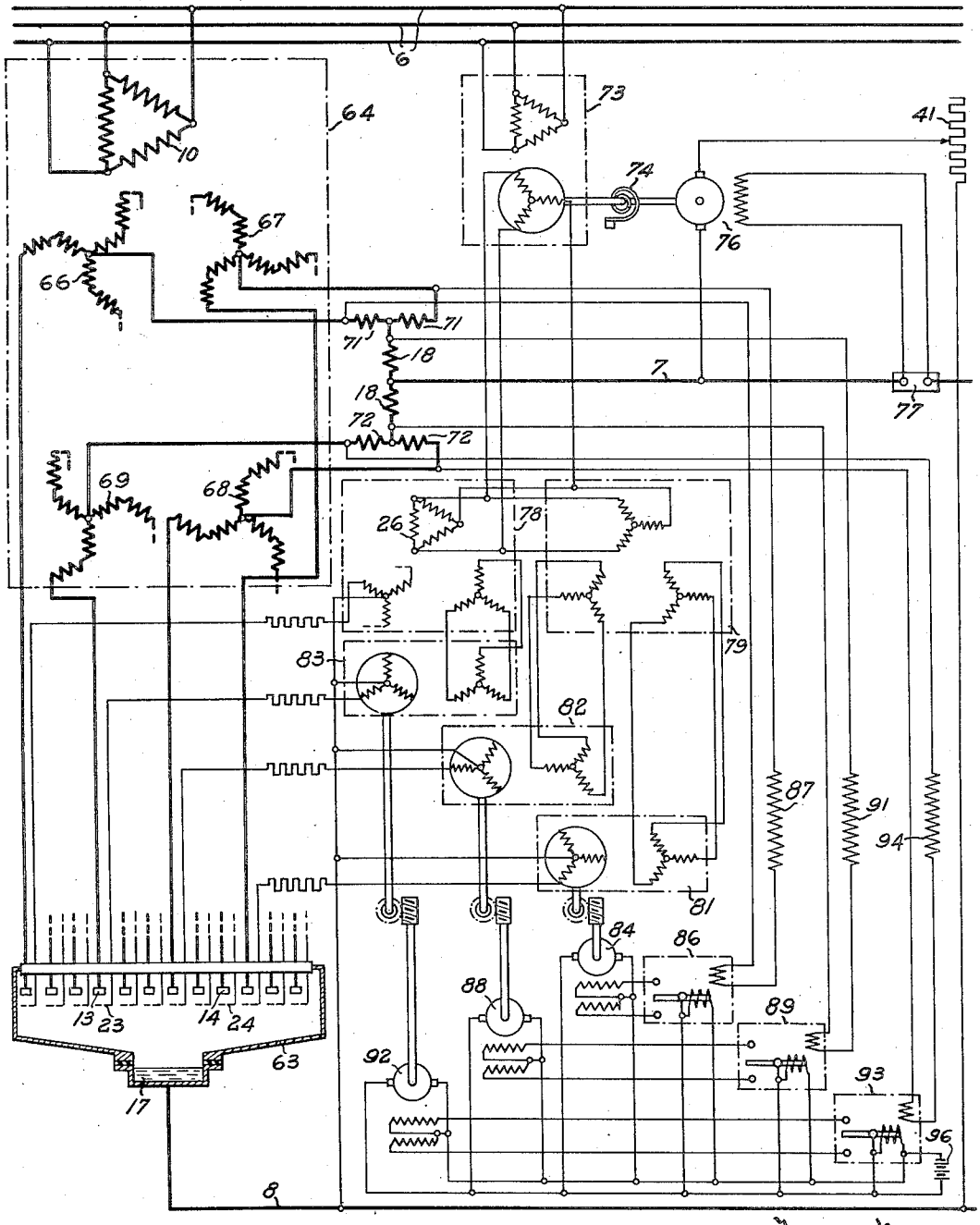


Fig. 3

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UNITED STATES PATENT OFFICE

2,038,505

RECTIFIER CONTROL SYSTEM

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Application August 7, 1933, Serial No. 683,940

22 Claims. (Cl. 175—363)

This invention relates in general to improvements in control systems and more particularly to means for maintaining a predetermined distribution of the flow of current in parallel circuits including electron discharge devices.

An electron discharge device may be employed in systems of different natures such as alternating current rectifying systems, direct current inverting systems, frequency changing systems, motor control systems, etc., presenting a plurality of parallel circuits for the flow of current. It is generally advantageous to obtain and maintain a simultaneous flow of current through the several parallel circuits of the system to improve the voltage characteristics and the efficiency thereof. Such simultaneous flow of currents may be inherently caused by the connections of the system and may result from the relative values of the impedances of the parallel circuits or from the use of current balancing means such as the so-called interphase transformers. The distribution of current in the parallel circuits may, however, occur in a manner differing from the desired manner either as a result of unbalanced impedances in the parallel circuits, or of unstable action of the control electrodes of the discharge devices, or as a result of the presence of harmonics in the voltage of alternating current circuits constituting part of the system. A variation of the distribution of current in the several circuits causes some of such circuits to be overloaded and is particularly objectionable when such circuits contain interphase transformers which become inoperative when such current unbalance causes the core of the interphase transformer to become saturated.

The desired current distribution may be maintained by supplementing the means designed to inherently produce such distribution with means responsive to the flow of current and operable to restore the desired current distribution when such distribution is disturbed. Such means should preferably cooperate with any means utilized for regulating the operation of the system and with any means utilized for causing the system to become inoperative upon the occurrence of serious disturbance therein.

It is therefore among the objects of the present invention to provide an improved control system for electron discharge devices whereby the desired current distribution is obtained and maintained in a plurality of electrically distinct circuits associated with the device.

Another object of the present invention is to provide an improved control system for electron discharge devices whereby the current distribution in the several circuits of the device is maintained invariable under all operating conditions.

Another object of the present invention is to provide an improved control system for electron discharge devices whereby the current distribution in the circuits of the device is maintained invariable irrespective of the imperfections of the means inherently designed to produce such current distribution.

Another object of the present invention is to provide an improved control system for electron discharge devices whereby the total flow of current through the devices is coordinately regulated with the flow of current through the several parallel circuits.

Another object of the present invention is to provide an improved control system for electron discharge devices whereby the flow of current through the device may be interrupted by means cooperating with the means controlling the distribution of current through the several circuits of the device.

Objects and advantages other than those above set forth will be apparent from the following description when read in connection with the accompanying drawings, in which:

Figure 1 diagrammatically illustrates one embodiment of the present invention applied to the control of a six-phase electron discharge device operable as an alternating current rectifier whereby the flow of current in two parallel circuits are maintained at the same values and whereby the total current flowing through the system is maintained at a constant value;

Figure 2 diagrammatically illustrates another embodiment of the present invention maintaining a predetermined current distribution between two six-phase rectifiers and maintaining the output voltage of such rectifiers at a constant value; and

Figure 3 diagrammatically illustrates another embodiment of the present invention maintaining equal flow of current through the four parallel circuits of a 12-phase rectifier and maintaining the output energy of such rectifier at a constant value.

Referring more particularly to the drawings by characters of reference, the reference numeral 6 designates an alternating current supply line herein represented as a 3-phase line. An output direct current line having a negative conductor 7 and a positive conductor 8 receives current from line 6 through a system comprising a transformer 9 having a primary winding 10 con-

nected with line 6 and having two 3-phase secondary windings 11 and 12. Windings 11 and 12 each comprise a plurality of phase displaced portions constituting a 6-phase system connected to form two neutral points. The several portions of winding 11 are each connected with an anode such as 13 of an electron discharge device 16 having a cathode 17 connected with conductor 8. The several portions of winding 12 are similarly connected with anodes such as 14 of device 16. The potential of cathode 17 will be taken herein as a datum and all potentials will be referred thereto unless otherwise stated. Any source of electromotive force having a terminal connected with the cathode will then have the other terminal thereof at a potential equal to such electromotive force, and the source therefore also functions as a source of potential for any circuits connected therewith. The neutral points of windings 11 and 12 are connected with conductor 7 through the windings of an interphase transformer 18 and through a shunt 19 having the midpoint thereof connected with conductor 7. The current flowing through conductor 7 is therefore offered two parallel circuits each comprising a portion of shunt 19 and of interphase transformer 18, one of the phases of the windings 11 and 12, and some of the anodes of device 16; both circuits terminating at cathode 17. Such circuits, designated by 21 and 22, are distinct in their electrical functions and may even be physically distinct if the anodes of each circuit are assembled in separate electron discharge devices having the cathodes thereof connected with conductor 8. Device 16 may also be replaced by a plurality of devices each containing a single anode and a cathode without, however, changing the nature of the operation thereof.

The flow of current through device 16 is controlled by a plurality of control electrodes such as 23, 24 severally associated with the anodes of the device. The control electrodes are energized at recurring potentials by means of a transformer 25 having a primary winding 26 energized from line 6 and having two secondary windings 27 and 28 each comprising a plurality of phase displaced portions connected to form a neutral point therefor. The voltage of windings 27 and 28 preferably have peak values smaller than the value of the voltage of line 7, 8. The neutral points of windings 27 and 28 are connected, through the contacts of a time delay relay 29, with the taps of two rheostats 30 and 31 associated with further rheostats 32, 33 and 34 to form a pair of voltage dividers connected between conductors 7 and 8. Rheostat 32 is constructed as a part of a regulator 36 operable to vary the point of connection of rheostat 32 with rheostat 33, such variation being effected in response to the appearance of current unbalance in circuits 21 and 22. To obtain this effect, regulator 36 is energized at the voltage between the terminals of shunt 19, either directly or through a reactor 37 which permits the passage therethrough of only the direct current component of the voltage. Rheostat 33 is constructed as a part of a second regulator 38 operating in response to the magnitude of the current flowing through a shunt 39 inserted in conductor 8, to vary the amount of rheostat 33 inserted in circuit with rheostats 30, 31, 32 and 34. The operation of regulator 38 may be adjusted by means of a rheostat 41 inserted in the energizing circuit thereof. Windings 27 and 28 may be disconnected from rheostats 30 and 31 by relay 29 which connects such windings between a capacitor 42 connected with conductor 8 and a high resistance resistor 43 connected with conductor 7. The coil of relay 29 is energized in response to the magnitude of the current of winding 10 by means of a current transformer 44.

As a result of the above connections, circuits 21 and 22, which each comprise one or more anodes and control electrodes constitute electrically distinct circuits which inherently tend to cause the flow therethrough of currents in a ratio of predetermined magnitude. Such circuits are operable to carry currents having maximum values in the same predetermined ratio and include distinct discharge controlling means including the control electrodes such as 23 and 24. Line 7, 8, transformer 25 and rheostats 30 to 34, constitute means including a source of potential energizing the control electrodes in such a manner that such control electrodes receive therefrom recurring potentials. Relay 29, which operates in response to the occurrence of abnormal conditions, overcomes the action of regulators 36 and 38 and cooperates with transformer 25 in controlling the energization of the control electrodes to cause the flow of current through device 16 to be extinguished. Regulator 36, which is responsive to the flow of current through circuits 21 and 22 and to the ratio of the magnitudes of such currents, tends to maintain the ratio of such currents invariable under all operating conditions, i. e., also when such conditions tend to cause the value of such ratio to vary. The regulator 36 controls the discharge controlling means in such a manner as to vary the times of application, in the supply voltage cycle, of control potentials to the two groups of control electrodes in opposite manner.

In operation, line 6 being energized and the system being connected as shown, and assuming that transformer 25 is so adjusted as to cause the system to operate to rectify alternating current received thereby from line 6 and to supply such rectified current to line 7, 8; the several portions of windings 11 and 12 and the associated anodes of device 16 sequentially carry currents which combine at cathode 17 to form direct current flowing to conductor 7. Interphase transformer 18 tends to cause such direct current to divide into two equal direct currents flowing though circuits 21 and 22. The flow of current through the several anodes of device 16 is released by the action of the associated control electrodes and is regulated in dependence upon the energization of such control electrodes from transformer 25 and line 7, 8. If the current flowing through conductor 8 is greater than is desired, regulator 38 varies the point of contact of the movable tap thereof with rheostat 33 to reduce the portion of rheostat 33 short circuited thereby. The negative direct current voltage component impressed on the control electrodes by the rheostats thereby increases causing the times of energization of all control electrodes to be retarded, with the result that the flow of current through device 16 and shunt 39 decreases as is well known in the art. Such action continues until the current is brought to the desired value, at which time regulator 38 remains in the position reached to maintain the flow of current at such value. If the flow of current is smaller than desired, the spring of regulator 38 returns the movable tap thereof toward the position shown to increase the short circuited portion of rheostat 33 and thereby decrease the direct current voltage component impressed on the con-

trol electrodes and increases the flow of current through device 16 to the desired value.

If the currents in circuits 21 and 22 are equal, the voltage drops in the two portions of shunt 19 are equal and no voltage is impressed therefrom on regulator 36. Such consideration neglects the comparatively small alternating current component of the current in circuits 21 and 22 which tends to cause the flow of alternating current through regulator 36, but such component may be neglected as the flow of alternating current through regulator 36 is prevented by reactor 37. In addition, such component would produce no torque as the field winding of the regulator is energized with direct current only. Regulator 36 then remains in the position shown and the direct current voltage components impressed on the neutral point of windings 27 and 28 are equal. If, for any reason, the current in circuit 21 becomes greater than the current in circuit 22, the voltage drops in the two halves of shunt 19 become unequal and a direct current flows from shunt 19 through the armature winding of regulator 36. Regulator 36 varies the position of the tap on rheostat 32 to cause a larger portion of rheostat 32 to be inserted in series with rheostat 30 and a correspondingly smaller amount of rheostat 32 to be inserted in series with rheostat 31. The direct current voltage component received by winding 27 is therefore greater than the component received by winding 28 and the flow of current through circuit 21 is decreased while the flow of current through circuit 22 is increased. Such action continues until full equality of the two currents is reestablished and regulator 36 then stops in the position reached thereby. Upon removal of the cause disturbing the distribution of flow of current through circuits 21 and 22, regulator 36 returns to the position shown. A similar but opposite operation of the regulator 36 occurs if the current through circuit 22 becomes greater than the current flowing through circuit 21.

During normal operation, capacitor 42 becomes charged at the voltage of line 7, 8 through resistor 43. Upon occurrence of a disturbance such as a short circuit in line 7, 8 or a backfire in device 16, the voltage of line 7, 8 collapses and capacitor 42 tends to discharge through the line, such action being, however, greatly retarded as the discharge current must flow through resistor 43. Upon occurrence of such disturbance, the resulting flow of excessive current through winding 10 causes the coil of relay 29 to receive an increased current from current transformer 44, and relay 29 immediately attracts the armature thereof, thereby substituting, for the negative direct current voltage component previously impressed on the control electrodes from the voltage divider connection above described, the full operating voltage of line 7, 8 obtained from capacitor 42. The control electrodes are thereby constantly energized at negative potentials as the voltage of capacitor 42 is greater than the peak value of the alternating voltages of windings 27 and 28. The further flow of current through device 16 is thus prevented and the backfire or short circuit is interrupted. After a predetermined time delay, relay 29 returns to the position shown to restore the system to the normal operating condition thereof.

In the embodiment illustrated in Figure 2, device 16 is represented as being connected with line 6 through a transformer 46 having winding 10 as the primary winding thereof, and having a 6-phase secondary winding 47 with the neutral point thereof directly connected with conductor 7. The control electrodes of device 16 receive alternating voltage components from a control transformer 48 having winding 26 as primary winding and provided with a 6-phase secondary winding 49. Winding 10 is connected with line 6 through a circuit breaker 51 having auxiliary contacts 52 controlling the connection of the closing coil of a circuit breaker 53 with a battery 54. Circuit breaker 53 connects winding 26 with line 6 and also connects the neutral point of winding 49 with rheostat 30. A second electron discharge device 56 is connected in parallel with device 16, the anodes of device 56 being severally connected with the phase portions of the secondary winding 55 of a second transformer 57 connected with line 6. The control electrodes of device 56 are energized by means of a second control transformer 58. The neutral point of the secondary winding of transformer 58 is connected with rheostat 31 from which it receives a direct current voltage component for the energization of the control electrodes of device 56. Devices 16 and 56 are connected with conductor 8 through a shunt 59 having two portions of relatively adjustable resistance values. The voltage terminals of shunt 59 are connected with the coil of regulator 36 in a manner similar to that illustrated for the connection of shunt 19 in Figure 1. Cathode 17 may be connected with shunt 59 through the contacts of a circuit breaker 61, auxiliary contacts 62 then preferably being provided on circuit breaker 61 to disconnect the coil of regulator 36 when circuit breaker 61 is opened.

In the present embodiment, the parallel circuits are constituted respectively by winding 47 with device 16 and by winding 55 with device 56. Such circuits may inherently tend to maintain the currents flowing therethrough at equal or at different values, and such values may be in a constant or in a variable ratio depending upon the no-load voltages of windings 47 and 55 and upon the impedances of the circuits and the methods of connection of the several elements thereof. Such circuits again include distinct discharge controlling means consisting of control electrodes such as 23 and 24 which are energized at recurring potentials from line 7, 8 and transformers 48 and 58. Regulator 36 has no action on the energization of the control electrodes of device 56 and only controls the energization of the control electrodes of device 16. Regulator 39 is no longer responsive to the magnitude of the current flowing through the system but is responsive to the magnitude of the output voltage of the system. Circuit breaker 61 is provided for opening the circuit of device 16 if so desired and the contacts thereof render regulator 36 inoperative when only device 56 is being used. It will be understood that the connections of device 56 with conductor 8 and with line 6 may also be effected through suitable circuit breakers to permit interruption of such connections. If more than two devices are to be connected in parallel, each device will be provided with means for energizing the control electrodes thereof and with a regulator in a manner entirely similar to that provided for device 56.

In operation, line 6 being energized and circuit breakers 51 and 61 being closed, devices 16 and 56 carry currents of magnitudes having a ratio determined by the no-load voltages of windings 47 and 55 and by the impedances of the circuits and the methods of connection of the

several elements thereof. In the present embodiment, regulator 38, being energized in response to the magnitude of the voltage of line 7, 8, controls the operation of devices 16 and 56 in such a manner as to maintain the voltage of line 7, 8 at a predetermined value. Such operation is otherwise similar to that described with respect to the embodiment illustrated in Figure 1. If the distribution of current between devices 16 and 56 is obtained in the desired manner, regulator 36 remains in the position shown. If, for any reason, the current flowing through device 16 is greater than desired relative to the current flowing through device 56, regulator 36 receives, from shunt 59, a voltage which causes such regulator to move the variable tap of rheostat 32 to increase the amount of such rheostat inserted in the circuit thereof. Such action causes the direct current voltage component impressed on winding 49 to increase thereby reducing the flow of current through device 16. Such action continues until the desired proportion between the currents through devices 16 and 56 is reestablished, whereupon regulator 36 remains in the position reached thereby. In the present embodiment, the flow of current through device 56 is not directly controlled by regulator 36 but, when the flow of current through device 16 is regulated by regulator 36, the flow of current through device 56 automatically varies in an opposite direction because the total flow of current through the device is determined by the load connected with line 7, 8. The action of regulator 36 will generally cause the average voltage of line 7, 8 to depart from the desired value, and such voltage is then restored to the desired value by regulator 38.

If it is desired to utilize only device 56 for the conversion of current, circuit breaker 61 is opened thereby interrupting the flow of current through device 16. Regulator 36 then becomes superfluous and is rendered inoperative by opening of auxiliary contacts 62 of circuit breaker 61. Under such conditions, it will generally be desired to entirely disconnect device 16 from line 6 by means of circuit breaker 51, and circuit breaker 53 then automatically disconnects transformer 48 from line 6 and from line 7, 8.

In the embodiment illustrated in Figure 3, the current is converted by means of a single electron discharge device 63 provided with twelve anodes and receiving current from line 6 through a transformer 64. Transformer 64 is provided with winding 10 as a primary winding and with four star connected secondary windings 66, 67, 68 and 69 constituting a 12-phase system. The neutral points of windings 66, 67, 68 and 69 are connected with conductor 7 through interphase transformer 18 and through two more interphase transformers 71 and 72. The control electrodes of device 63 are represented as receiving only alternating voltages from a phase shifter 73 connected with line 6. Phase shifter 73 may be constructed similarly to a wound rotor induction motor, and the armature thereof is prevented from rotating by means of a spring 74. The relative position of the armature and of the stator of the phase shifter may be adjusted by a torque motor 76 having the armature thereof energized at the voltage of line 7, 8 through rheostat 41 and having the field thereof energized in response to the magnitude of the current flowing through conductor 7 by means of a shunt 77.

The armature of phase shifter 73 supplies current to the primary windings of two control transformers 78 and 79 having the windings thereof so connected as to supply 12-phase currents to the control electrodes of device 63. For this purpose, the secondary windings of transformers 78 and 79 are each constituted of two 3-phase windings severally energizing the control electrodes associated with the anodes receiving current from windings 66, 67, 68 and 69 respectively. The control electrodes associated with the anodes supplied from winding 66 are directly connected with one secondary winding of transformer 78. The remaining control electrodes are connected with transformers 78 and 79 through phase shifters 81, 82 and 83. The position of the armature of phase shifter 81 may be adjusted by means of a reversible motor 84 which may be energized from a battery 96 through a polarized relay 86 to cause rotation thereof in the one or in the other direction. The operating coil of relay 86 is connected through a reactor 87 across the terminals of interphase transformer 71 in a manner similar to the connection of the coil of regulator 36 with shunt 19 in Figure 1. The operation of phase shifter 82 is similarly controlled by a motor 88 and a relay 89 connected across the terminals of interphase transformer 18 through a reactor 91, and the operation of phase shifter 83 is controlled by means of a rotor 92 and of a relay 93 connected across the terminals of interphase transformer 72 through a reactor 94.

As a result of the above described connections, windings 66, 67, 68 and 69, together with the connections thereof with the interphase transformers and with the anodes of device 63, constitute electrically distinct circuits tending to maintain therethrough flow of current of equal values and having equal maximum values. Phase shifters 81, 82 and 83, which are operated in response to the ratios of the currents flowing through the above circuits, maintain the flow of such currents equal independently of any operating conditions tending to disturb such equality. The phase shifters are operated in response to the flow of current through the circuits taken in pairs and are one less in number than the number of such circuits. The control electrodes are energized by means comprising line 6 as a source of recurring potentials and of phase shifters 73, 81, 82 and 83 and transformers 78 and 79. Phase shifter 73 and motor 76 operate in response to the flow of current through device 63, and in response to the output voltage of line 7, 8 and therefore in response to the amount of energy flowing through the system to regulate the flow of current therethrough.

In operation, assuming the system to be connected as shown and line 16 to be energized, if the flow of current through windings 66, 67, 68 and 69 are equal, phase shifters 81, 82 and 83 remain in a position such that the control electrodes of device 63 are energized at voltages of uniform phase intervals. If the currents through windings 66 and 67 differ in value, a direct current voltage component appears across the terminals of interphase transformers 71 and is impressed on the coil of relay 86. Relay 86 closes the one or the other contact thereof and energizes motor 84 to cause rotation thereof in the one or in the other direction and thus adjusts phase shifter 81 to advance or retard the voltages delivered thereby. The flow of current through winding 67 is thereby increased or reduced until such current is brought to the value of the current flowing through winding 66. When such equality of

the two currents is obtained, the direct current voltage component across interphase transformer 71 disappears, relay 86 returns to the position shown, and motor 84 and phase shifter 81 remain in the position reached thereby. In a similar manner, if the currents flowing in windings 68 and 69 differ, a direct current voltage component appears across the terminals of interphase transformer 72 and phase shifter 83 controls the flow of current through winding 69 to bring such current to the value of the current through winding 68. If the total current flowing through windings 66 and 67 differs from the total current flowing through windings 68 and 69, a direct current voltage component appears across the terminals of interphase transformer 18 causing phase shifter 82 to operate to control the flow of current through winding 68 until the currents flowing through the two portions of interphase transformer 18 become equal. Such operation of phase shifter 82 may cause the currents flowing through winding 68 and 69 again to become unequal, and such action is then corrected by phase shifter 83 in the manner described above. If the energy output of the system is greater than the desired value, motor 76 shifts the position of the armature of phase shifter 73 in a manner such as to retard the phase of the voltages applied on all the control electrodes of device 63 to reduce the output of such device, such action continuing until such output is reduced to the desired value, whereupon phase shifter 73 remains in the position reached thereby. If the output of the system is below the desired value, spring 74 returns the armature of phase shifter 73 toward the original position thereof to increase the output of the system to the desired value.

Although but a few embodiments of the present invention have been illustrated and described, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

It is claimed and desired to secure by Letters Patent:

1. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits tending to cause flow therethrough of currents of magnitudes in ratios of predetermined values, and means responsive to the ratios of the magnitude of the currents taken in pairs for maintaining the ratios of the magnitudes of the currents of the respective pairs at the predetermined values.

2. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits each including distinct discharge controlling means, and means responsive to the ratios of the magnitude of the currents taken in pairs and controlling the second said means to maintain the ratios of the magnitudes of the currents of the respective pairs at predetermined values.

3. In a system for controlling the flow of electric current, electron discharge means having a plurality of electrically distinct circuits each comprising an anode and an associated control electrode, means for energizing said control electrodes, and means responsive to the ratio of the magnitudes of the currents flowing through said circuits taken in pairs and controlling the operation of the second said means to maintain the ratios of the magnitude of the currents of the respective pairs at predetermined values.

4. In a system for controlling the flow of electric current, electron discharge means having a pair of electrically distinct circuits each comprising an anode and an associated control electrode, means including a source of potentials for impressing recurring potentials on each said control electrodes, and means responsive to the ratio of the magnitudes of the currents flowing through said circuits for controlling the times of application of said recurring potentials to each of said control electrodes in opposite manner to maintain the ratio of the magnitudes of the currents flowing through said circuits at a predetermined value.

5. In a system for controlling the flow of electric current, electron discharge means having a pair of electrically distinct circuits each comprising an anode and an associated control electrode, means including a source of potentials for impressing recurring potentials on each said control electrodes, and means responsive to the ratio of the magnitudes of the currents flowing through said circuits for controlling the times of application of said recurring potentials to one of said control electrodes to maintain the ratio of the magnitudes of the currents flowing through said circuits at a predetermined value.

6. In a system for controlling the flow of electric current, electron discharge means having a plurality of electrically distinct circuits each comprising an anode and an associated control electrode, means including a source of potentials for impressing recurring potentials on each said control electrodes, and means one less in number than the number of said circuits and severally responsive to the ratios of the magnitudes of the current flowing through said circuits taken in pairs for controlling the times of application of said recurring potentials to all but one of said control electrodes to maintain the ratio of the magnitudes of the currents flowing through said circuits at a predetermined value.

7. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, means responsive to the flow of current through said circuits for maintaining the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, and means responsive to an operating condition of said discharge means and cooperating with the second said means to control the operation of said discharge means.

8. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, means responsive to the flow of current through said circuits for maintaining the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, and means responsive to the magnitude of the output voltage of said discharge means and cooperating with the second said means to control the flow of current through said discharge means.

9. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, means responsive to the flow of current through said circuits for maintaining the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, and means responsive to the mag-

nitude of the current flowing through said discharge means and cooperating with the second said means to control the flow of current through said discharge means.

10. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, means responsive to the flow of current through said circuits for maintaining the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, and means responsive to the magnitude of the energy flow through said means cooperating with the second said means to control the flow of current through said discharge means.

11. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, means responsive to the flow of current through said circuits for maintaining the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, means for opening one of said circuits, and means controlled by the last said means to cause the second said means to cease to respond to the current conditions in said one of said circuits.

12. In a system for controlling the flow of electric current, electron discharge means comprising a plurality of electrically distinct circuits, discharge controlling means for said discharge means, means responsive to the flow of current through said circuits and controlling the second said means to maintain the ratios of the magnitude of the currents in said circuits at predetermined values under all operating conditions of said system, means responsive to an operating condition of said discharge means and cooperating with the third said means to control the operation of said discharge means, and means responsive to the occurrence of abnormal conditions in said system for controlling the second said means and overcoming the action of the last said two means for causing interruption of the flow of current through said system.

13. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, and means responsive to the ratio of the magnitudes of the currents flowing through the circuits to apply a potential from said direct current line to said transformer for controlling the action of the control electrodes to maintain the predetermined ratios of current flow.

14. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, means responsive to the ratio of the magnitudes of the currents flowing through the circuits to apply a potential from said direct current line to said transformer for controlling the action of the control electrodes to maintain the predetermined ratios of current flow, and a relay responsive to abnormal conditions in said discharge device to disconnect said means from said transformer.

15. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, means responsive to the ratio of the magnitudes of the currents flowing through the circuits to apply a potential from said direct current line to said transformer for controlling the action of the control electrodes to maintain the predetermined ratios of current flow, a capacitor connected with said direct current line, and a relay responsive to abnormal conditions in said discharge device to disconnect said means and to connect said capacitor to said transformer to cause cessation of flow of current through the system.

16. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, a rheostat variable in response to the ratio of the magnitude of the currents flowing through the circuits to apply a potential from said direct current line to said transformer for controlling the action of the control electrodes to maintain the predetermined ratios of current flow, and a rheostat variable in response to variations in current magnitude in said direct current line and cooperating with the first said rheostat to maintain a constant current flow through the circuits in the predetermined ratio.

17. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, a rheostat variable in response to the ratio of the magnitude of the currents flowing through the circuits to apply a potential from said direct current line to said transformer for controlling the action of the control electrodes to maintain the predetermined ratios of current flow, and a rheostat variable in response to variations in voltage magnitude in said direct current line and cooperating with the first said rheostat to maintain a constant current flow through the circuits in the predetermined ratio.

18. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer hav-

ing a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, and means responsive to the voltage of said direct current line for controlling the action of the control electrodes in one of the circuits upon interruption of the other of the circuits.

19. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, means for interrupting one of the circuits, and means responsive to the voltage of said direct current line for controlling the action of the control electrodes in one of the circuits upon interruption of the other of the circuits.

20. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, and means responsive to the magnitude of the total energy flow from all of said electrically distinct circuits through said direct current line to vary the phase of the potentials applied to the control electrodes by said transformer.

21. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, means responsive to the magnitude of the energy flow through said direct current line to vary the phase of the potentials applied to the control electrodes by said transformer, and means responsive to the ratios of the magnitude of the current flow through said circuits to cooperate with the first said means in varying the phase of the potentials applied to the control electrodes by said transformer.

22. In a system for controlling the flow of electric current, a source of alternating current, electron discharge means having a plurality of electrically distinct circuits each comprising a winding connected with said source and with an anode and a control electrode, a transformer having a winding thereof connected with said source and with the control electrodes to impress recurring potentials on each of the control electrodes, a direct current line supplied by said discharge means, means for varying the phase of the potentials applied to the control electrodes by said transformer, and relays responsive to the ratios of the magnitudes of the currents flowing through the circuits for controlling the operation of said phase varying means.

HAROLD WINOGRAD.