April 24, 1951 R. L. LONGINI 2,549,831

CONVERSION SYSTEM

Filed May 21, 1948 4 Sheets-Sheet 1

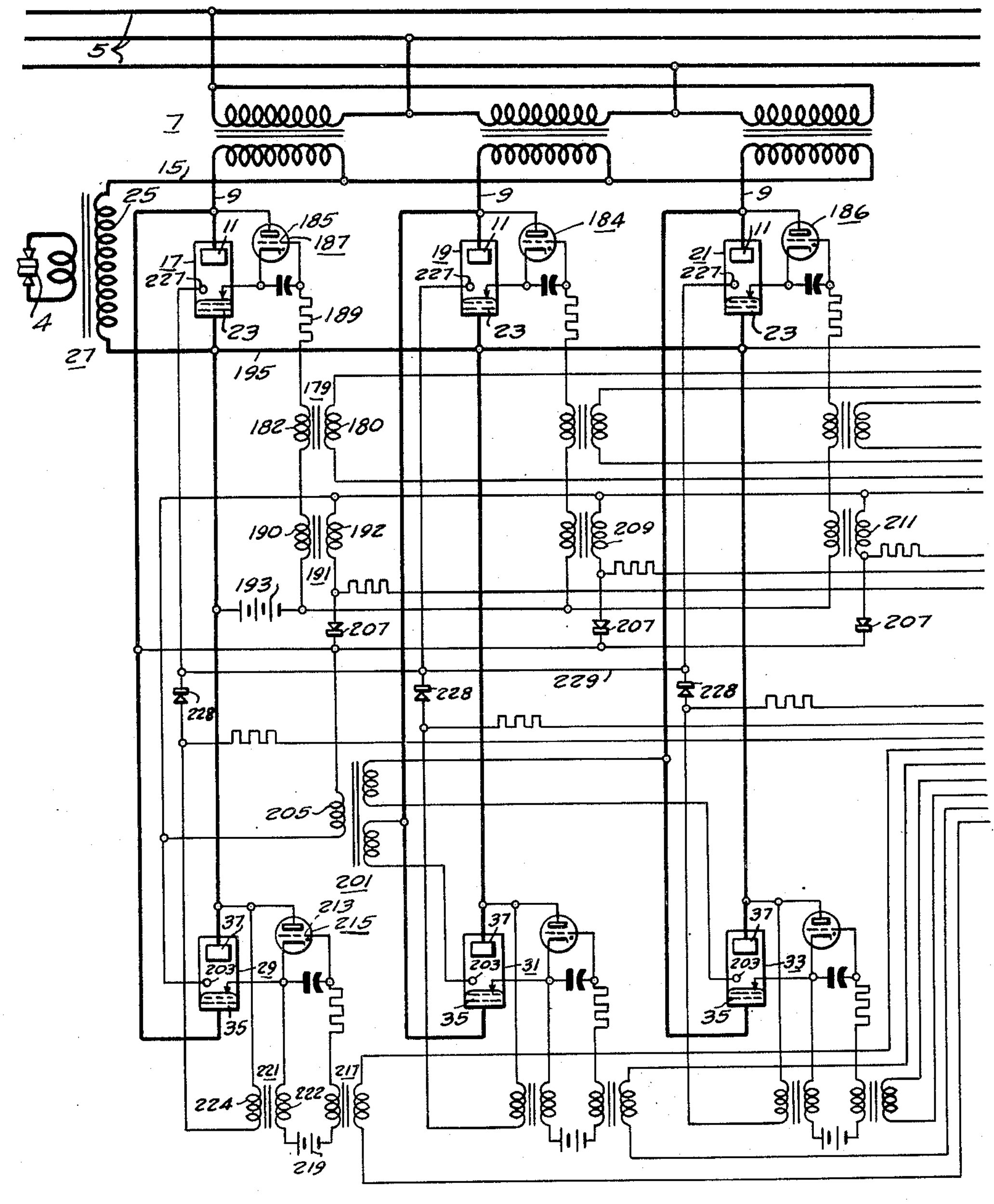

Fig. 1a.

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Filed May 21, 1948 4 Sheets-Sheet 2

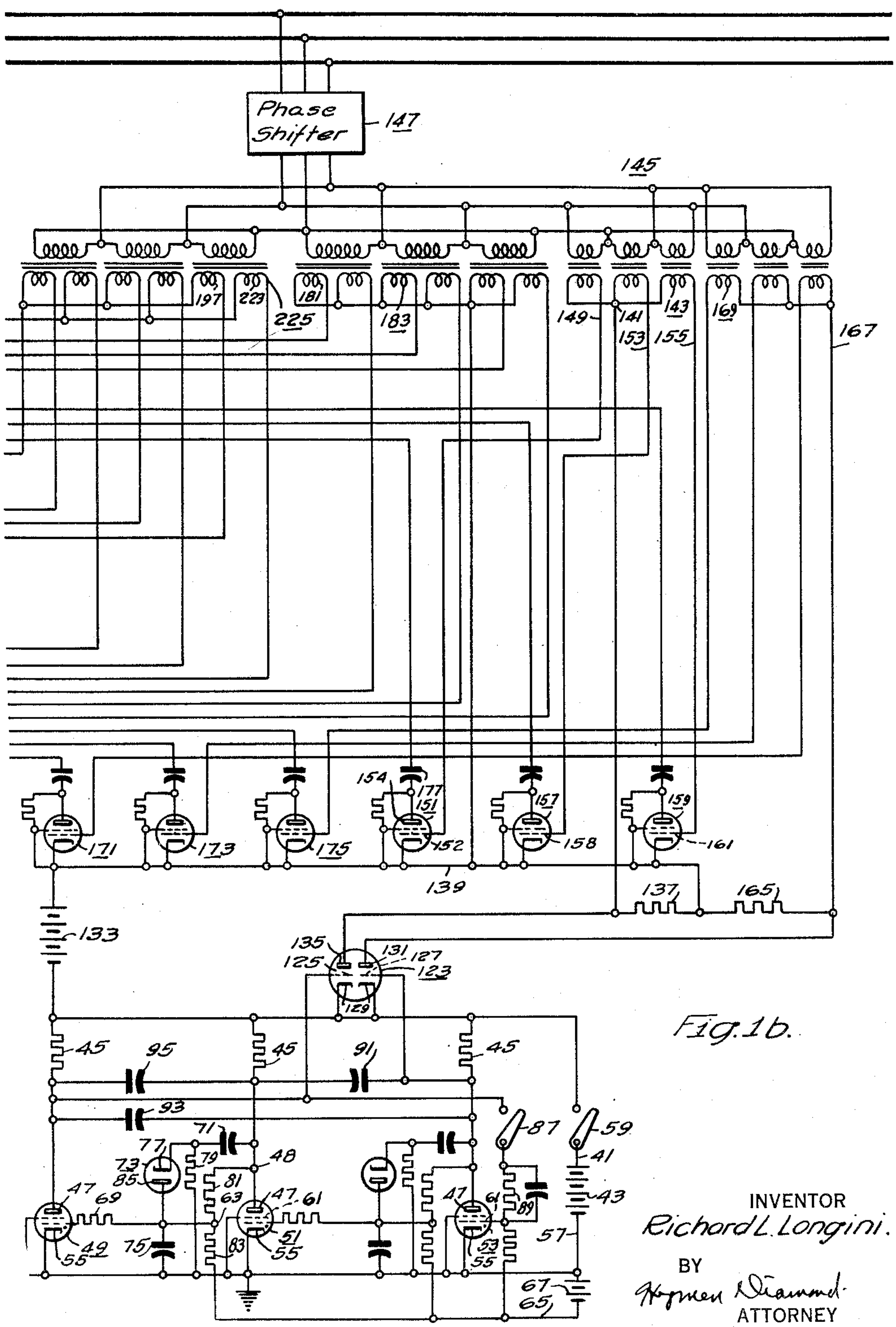

Fig.1b.

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CONVERSION SYSTEM

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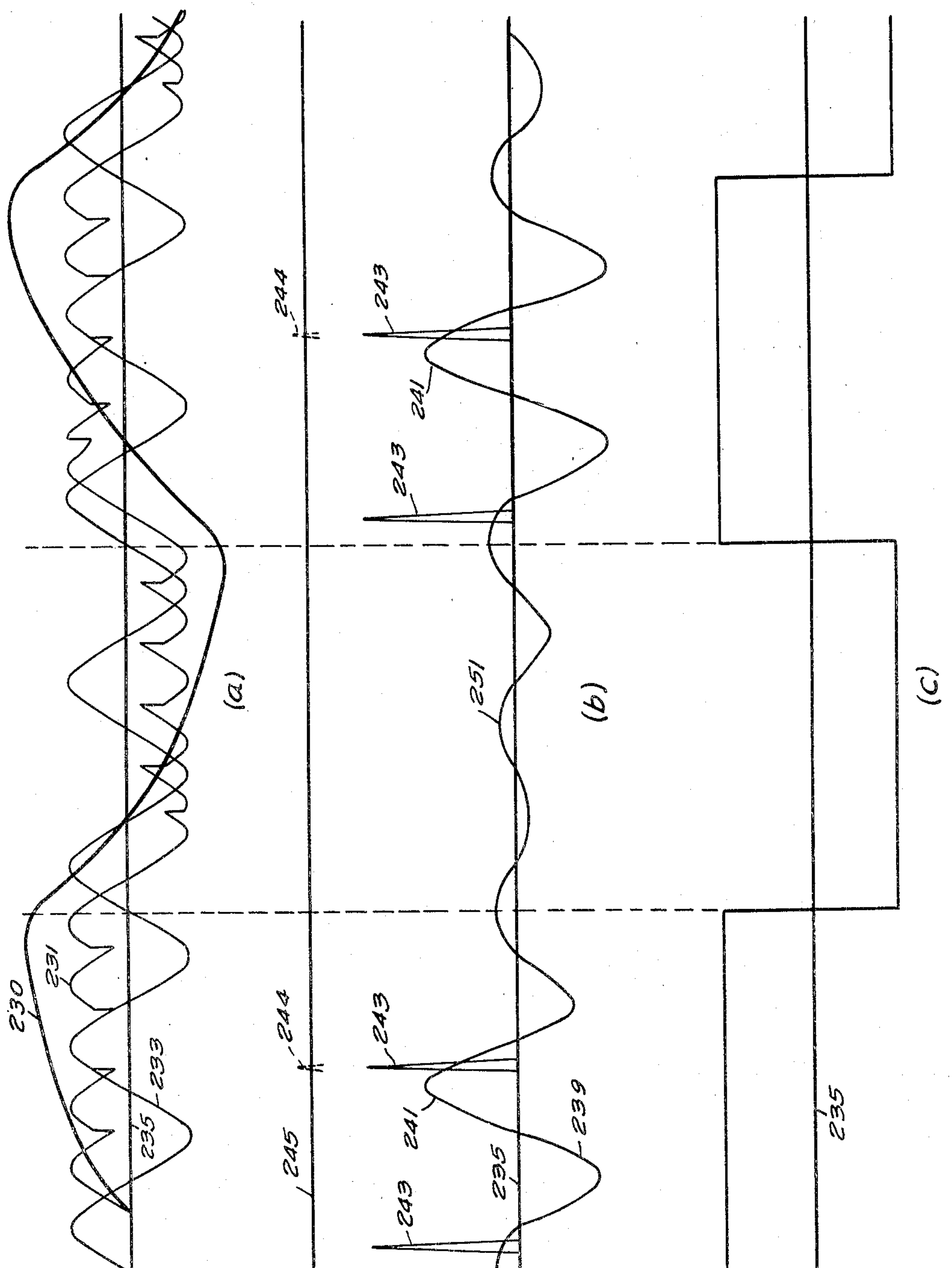

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Fig. 2.

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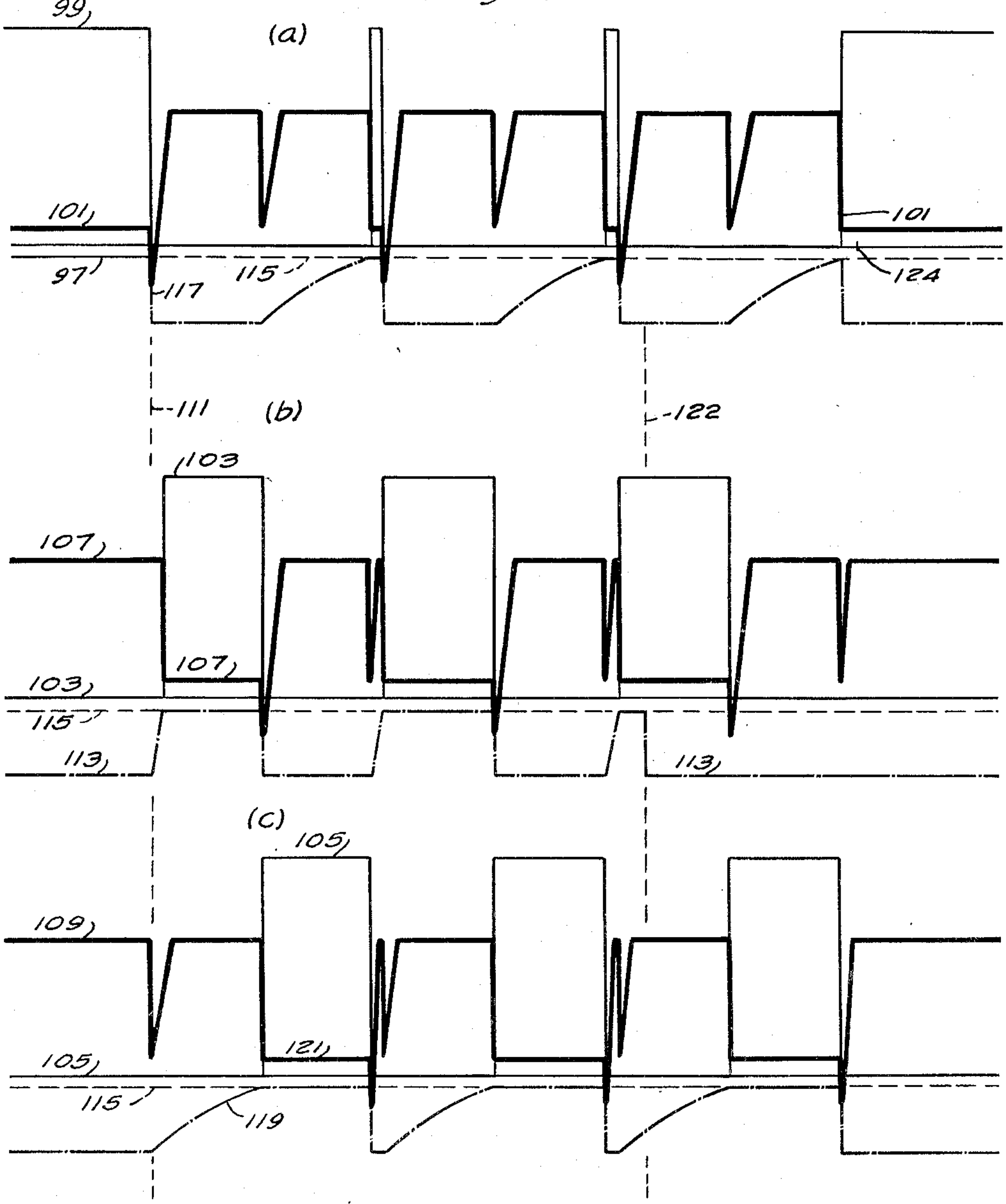
CONVERSION SYSTEM

Filed May 21, 1948 4 Sheets-Sheet 4

Fig. 3.



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2,549,831

UNITED STATES PATENT OFFICE

2,549,831

CONVERSION SYSTEM

Richard L. Longini, Pittsburgh, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application May 21, 1948, Serial No. 28,304

18 Claims. (Cl. 315—138)

My invention relates to an electronic control system, and it has particular relation to a control system useful in resistance welding.

In one of its specific aspects, my invention involves a welding system in which single phase alternating current for welding is derived from a polyphase source. In control systems constructed and operated in accordance with the prior art, of which I am aware, current of one polarity is supplied through a first plurality of valves to the welding transformer and current of the opposite polarity through a second plurality of valves. By operation of a control system these two pluralities of valves are rendered conductive alternately at the periodicity of the single phase current. During the conductive intervals of any plurality, each of its valves conducts in its turn. At the end of a half period of the single phase, one of the valves of the first plurality is conductive. The first valve of the other plurality is now rendered conductive. To avoid a short-circuit the last valve of the first plurality should be non-conductive before the first valve of the second plurality becomes conductive. The last valve of the first plurality becomes non-conductive when the potential between its anode and cathode becomes zero or negative. Since the inductance of the welding transformer is considerable, the source voltage corresponding to the last conductive valve reaches a negative magnitude while the last valve is still conductive. The selection of the valves and the timing of their conductivity in such manner as to take into account the reactive overlap of conductivity is not practicable. Variations in the source potential, in the material to be welded, in the extent to which the material is inserted in the throat of the welder interfere with the preset operation of a selection and timing system and damaging short circuits result.

It is, accordingly, an object of my invention to provide a protective circuit for a polyphase to single phase valve conversion system which will prevent the power source from becoming short-circuited.

Another object of my invention is to provide a polyphase to single phase valve conversion system in which short-circuiting of the supply by the valves will not occur.

A general object of my invention is to provide a new and improved control system for changing polyphase alternating current to single-phase alternating current.

A further object of my invention is to provide a new and improved circuit arrangement for changing polyphase alternating current of one frequency to a single-phase alternating current of a lower frequency.

A further object of my invention is to provide a new and improved circuit for changing a polyphase alternating current of one frequency to a single-phase alternating current of a lower frequency in which the kilovolt-amperes demand will be substantially lower than for prior systems.

More specifically, it is an object of my invention to provide a novel control system useful for resistance welding in which single phase current is supplied from a polyphase supply.

In the prior art systems, difficulty has also been experienced with the timing circuit which controls the conductivity of the first and second pluralities of valves. I found that the timing oscillations which these circuits produce vary in frequency according to the length of time during which the circuit operates. This variation produces a corresponding variation in the load current. Since the frequency of the load current from such a timer is dependent upon the time required for the grids of each of its plurality of valves to reach a firing potential, the frequency is also dependent on the lowest potential reached by the grids. In this type of timer the grids of its plurality of valves will not begin to rise from a uniform low potential until some time has elapsed. Further, when the control switch is opened to discontinue the supply of load current, the timer stops at a random instant in its output period. The operation generally terminates with a voltage remaining in the load circuit. This operation would leave a load transformer saturated.

It is, accordingly, a further purpose of my invention to provide a timing circuit which shall produce timing oscillations of uniform frequency throughout its operation.

Another object of my invention is to provide a timing circuit which, when the timing is to be discontinued, shall supply no appreciable timing potential.

In accordance with my invention, the conductivities of the valves of each of the pluralities are, in fact, mutually controlled from auxiliary anode circuits of the valves of the other plurality. So long as a valve is conductive its auxiliary anode circuit carries current. A potential derived from this current blocks the conductivity of any valve in the other plurality.

In accordance with my invention a timer is provided in which the period of the timing current is dependent on the time required for the grids of its plurality of valves to reach a firing potential, and each grid rises through the same potential difference throughout the operation of the timer.

The novel features of my invention are set forth with more particularity in the accompanying claims. The invention itself, however, with respect to the details thereof, together with its additional objects and advantages, may be better understood from the following description of a specific embodiment with reference to the accompanying drawings, in which:

Figures 1*a* and 1*b* together are a schematic circuit diagram of a control system of a preferred embodiment of my invention;

Fig. 2 is a series of graphs illustrating the operation of the system shown in Fig. 1.

Fig. 3 is another series of graphs illustrating the operation of the system shown in Fig. 1.

In the apparatus shown in Fig. 1, a material **4** to be welded receives energy from three-phase supply lines **5** through a three-phase supply transformer **7**. The supply transformer **7** has an output terminal **9** for each phase and a common return terminal **15**. Three main electric discharge valves **17**, **19** and **21** of the arc-like type, such as ignitrons, are provided to correspond with the three-phase voltages, each main valve having an anode **11** connected to the corresponding output phase terminal **9** of a supply transformer **7** and a cathode **23** connected through the primary **25** of the welding transformer **27** to the common return terminal **15**. These valves **17**, **19** and **21** conduct current of one polarity through the welding transformer.

A second group of three main electric discharge valves **29**, **31**, **33** of the arc-like type, such as ignitrons, are provided to conduct current of the opposite polarity. Each of the latter main valves has a cathode **35** connected to the corresponding output phase terminal **9** of the supply transformer **7** and an anode **37** connected to the common return terminal **15** of the supply transformer **7** through the primary winding **25** of the welding transformer **27**.

The sequence and time of firing of the six ignitrons **17**, **19**, **21**, **29**, **31** and **33** is controlled by a control circuit comprising six auxiliary valves **151**, **157**, **159**, **171**, **173** and **175** of the arc-like type, such as thyratrons. These auxiliary valves are supplied through a control transformer **145** and a phase shifter **147** from the main supply **5**. The conductivity of the six auxiliary thyratrons is controlled from a multivibrator.

The action of the control circuit is such that first the three ignitrons **17**, **19**, and **21** become conductive in succession, passing current of one polarity through the welding transformer for a preselected interval of time; then the three ignitrons **29**, **31**, and **33** become conductive successively, passing current of the opposite polarity through the welding transformer for the same interval of time. Thus the welding transformer receives single-phase alternating current of the desired frequency.

In the multivibrator circuit the positive terminal **41** of a first source **43** of direct current shown symbolically in Fig. 1*b* as a battery, is connected through resistors **45** to the anode **47** of each of three valves **49**, **51**, **53** of the arc-like type, such as thyratrons. The cathode **55** of each thyratron is connected to the negative terminal **57** of the first source **43** of direct current which is at ground potential. Prior to initiation of operation of the multivibrator, a heating current is supplied to the filaments of the various valves and tubes of the entire welding circuit by conventional means which, for purposes of clarity in the drawings, are not illustrated.

The grid **61** of the second thyratron **53** is connected through an impedance **89** to the anode **47** of the third thyratron **49**. The positive terminal **47** of the first thyratron **51** is connected through a voltage divider to the negative terminal **65** of the second source **67** of direct current, shown in Fig. 1*b* as a battery. A central point **63** in the voltage divider is connected through a resistor **69** to the grid of the third thyratron. The positive terminal **47** of the first thyratron **51** is connected through a capacitor **71**, a diode tube **73**, and a second capacitor **75** to ground. The capacitor **71** is connected through a resistor **79** to ground.

When the first thyratron **51** is in a non-conductive state, the positive terminal **48** of the voltage divider is at a high potential of, for example, 150 volts. This produces a positive bias on the grid of the third thyratron **49** sufficient to allow the third thyratron **49** to fire if the first thyratron **51** were not conductive.

At the beginning of operation the control switch **59** is closed causing the first thyratron **51** to fire. When the first thyratron **51** first becomes conductive, the potential of its anode **47** is decreased to a magnitude equal to the voltage drop of the thyratron. If the supply **43** provides 150 volts, the decrease is of the order of 142 volts. The value of the first and second resistors **81** and **83**, respectively, of the voltage divider and the two condensers **71** and **75** is such that the anode **85** of the diode tube **73** which is prevented from changing potential rapidly by the presence of the second condenser **75** is at a higher potential than the cathode **77** which is connected through a first capacitor **71** to the anode **47** of the first thyratron **51**. Since there is a potential difference of the proper polarity across the diode tube **73** sufficient to cause conduction, the diode tube **73** begins to conduct current as soon as the first thyratron **51** becomes conductive. Thus, as soon as the first thyratron **51** becomes conductive, a surge of current passes through the diode tube **73** causing the anode **85** of the diode tube **73**, and the grid of the third thyratron **49** connected to it, rapidly to reach an equilibrium potential determined by the capacity of the first and second capacitors **71** and **75**, respectively.

The capacity of the first and second capacitors **71** and **75** and the first and second resistors **81** and **83** is such that the equilibrium potential at the point **85** between the diode tube **73** and the second condenser **75** is the same as the equilibrium potential between the first and second resistors **81** and **83**. For this to be the case, the following relation must hold approximately:

$$\frac{C_1}{C_2}=\frac{R_2}{R_1}=\frac{E_2}{E_1}$$

where

C_2=capacity of the second capacitor **75**

C_1=capacity of the first capacitor **71**

E_1=voltage between the anode **47** of the first thyratron **51** and ground when the thyratron **51** is conductive

E_2=voltage across the second battery **67**

R_1=resistance through the resistor **81** connected to the anode of the first thyratron

R_2=The resistance through the resistor **83** connected to the negative side of the second battery

These equations state the desired relationship only approximately, because they make no allowance for either the resistor **79** connected between the cathode **77** of the diode tube **73** and ground or the diode tube **73** across which a potential exists, but it gives approximately the relationship required. If the two resistors **81** and **83**, the two condensers **71** and **75** and the two voltages 67 and 43 are related substantially as given above, no current will flow between the central point 63 in the voltage divider and the point 85 between the two condensers. The grid 69 of the third thyratron 49 will then remain at one potential until the voltage E_1 is changed.

When it is desired to begin the actual welding operation, the starting switch 87 is closed. This starting switch 87 connects the grid 61 of the second thyratron 53 through an impedance 89 to the anode 47 of the now non-conductive third thyratron 49, thus raising the potential of the grid 61 to a value sufficiently high to cause the second thyratron 53 to fire. The second thyratron 53 then charges a capacitor 91 to extinguish the first thyratron 51.

After the first thyratron 51 is extinguished, the potential difference across the first thyratron 51 increases greatly. Its first capacitor 71 is charged through a resistor 79 and its second capacitor 75 is charged through the resistors 81 and 83 of the voltage divider. A certain time delay determined by the time constants of the charging networks is involved in this charging process. During the time that the capacitors 71 and 75 are being charged, the second thyratron 53 continues conductive. As soon as the capacitors 71 and 75 have charged sufficiently to raise the potential of the grid in the third thyratron 49 to a high enough value to allow the third thyratron 49 to fire, the third thyratron 49 fires, charging capacitor 93 to extinguish the second thyratron 53. The grid circuit of the first thyratron 51 is connected to the anode circuit of the second thyratron 53 in the same manner as the grid circuit of the third thyratron 49 is connected to the first thyratron 51. The same voltage, capacity, resistance relations hold in the grid circuit of the first thyratron 51 as previously described for the circuit in the grid of the third thyratron 49.

When the second thyratron 53 first becomes conductive, it lowers the potential of the control grid on the first thyratron 51 in the same manner as the first thyratron 51 had previously lowered the potential on the control grid of the third thyratron 49. When the third thyratron 49 becomes conductive, causing the second thyratron 53 to become non-conductive, the grid potential on the first thyratron 51 begins to rise toward the critical value required to allow the first thyratron 51 to become conductive after a time interval predetermined by the time constant networks in the circuit of thyratron 53, the first thyratron 51 is rendered conductive. The third thyratron 49 is now extinguished by the charging of the capacitor 95 connecting the anodes 47 of thyratrons 49 and 51 respectively. With the starting switch 87 closed, the control grid 61 on the second thyraton 53 is always at the potential of the anode of the third thyratron 49. The control grid of the second thyratron 53, therefore, immediately rises to the potential of the anode of the now non-conductive third thyratron 49 and the second thyratron 53 fires immediately after the third thyratron 49 is extinguished. The second thyratron 53 extinguishes the first thyratron 51 through the capacitor 91 connecting their anodes 47.

The sequence of operation continues as described until the starting switch 87 is opened. The starting switch 87 will be manually opened at a random instant in a period of the multivibrator period. Since the opening of the starting switch 87 serves only to prevent the second thyratron 53 from becoming conductive and does not affect the operation of the other thyratrons, the sequence of operation continues until the time when, with switch 87 closed, the second thyratron would become conductive. The second thyratron 53 cannot become conductive because switch 87 is open and the change in the conductivities of the valves is stopped when the first thyratron 51 becomes conductive. The latter continues conductive until the control switch 59 is opened.

The voltage relationships which result from this sequence of operations can conveniently be described with reference to Fig. 3(*a*), (*b*) and (*c*). In these graphs the output voltage of each of the three tubes, the voltage at all times across each of the tubes, and the grid potential on each tube are plotted as a function of time. It must be realized that, for the sake of clarity, no minor variations of potential are shown in these graphs. Voltage is plotted vertically and time horizontally. The time axis for each curve is the same, so that directly above a point representing a certain time on curve *c* are points on curves *a* and *b* which represent the same instant of time. The voltages relating to the first thyratron 51 are shown in Fig. 3(*a*); those relating to the second thyratron 53 in 3(*b*), and those relating to the third thyratron 49 in 3(*c*).

When the control switch 59 is closed, the grid potential of the first thyratron 51 represented by curve 97 is high enough to permit firing, and the first thyratron 51 becomes conductive. The output voltage from the first thyratron 51 represented by curve 99 becomes high and the voltage across it represented by curve 101 becomes low. The output voltage (curves 103 and 105) from the second and third thyratrons 53 and 49 is zero. The voltage curves 107 and 109 across the second and third thyratrons 53 and 49 is high because they present an open circuit.

At the instant 111 when the starting switch 87 is closed, the grid potential (curve 113) of the second thyratron 53 is raised to its critical value 115 and the second thyratron 53 fires. The output voltage (curve 103) which is measured across resistor 45 from the second thyratron 53 rises to a high value. The voltage (curve 107) across the second thyratron 53 drops to a low value 117, momentarily depressing the voltage across the first thyratron 51 to a negative value, and extinguishing the first thyratron 51.

While the second thyratron 53 is conductive, the grid potential (curve 119) of the third thyratron 49 is rising toward its critical firing potential. When the potential (curve 119) of the grid 69 of the third thyratron 49 reaches its critical potential 115, the third thyratron 49 becomes conductive. The voltage (curve 121) across the third thyratron 49 drops to a low value and momentarily renders negative the voltage (curve 107) across the second thyratron 53, extinguishing the second thyratron 53.

While the third thyratron 49 is conductive, the grid potential (curve 97) of the first thyratron 51 is rising toward its critical firing potential 115. When the potential (curve 97) of the grid of the first thyratron 49 reaches the critical value 115, the first thyratron 49 becomes conductive. The voltage across the first thyratron 49 drops to a low value 117 extinguishing the third thyratron 51. When the third thyratron 51 is extinguished, the potential (curve 113) of the control grid 61 of the second thyratron 53 quickly reaches its critical potential 115, and the second thyratron 51 becomes conductive.

This sequence of operation continues until the instant 122 when the starting switch 87 is opened. The opening of this switch acts only to lower the potential (curve 113) of the control grid 61 on the second thyratron 53 sufficiently to prevent the second thyratron 53 from firing. As shown in Fig. 3, the sequence of operations continues until it is again time 124 for the second thyratron 53 to fire. At that time 123, the second thyratron 53 does not fire and extinguish the first thyratron 49 as it would have done in the normal sequence of operation, but the first thyratron 49 continues conductive as long as the potential 101 exists across it. Operation will always end with the first thyratron conductive.

On the basis of prior art a multivibrator would be designed using only two thyratrons, both of which would be connected to output leads. In such an arrangement operation of the multivibrator would generally be terminated while one thyratron is conductive, and a potential difference would remain across the output leads. The second thyratron in my multivibrator is not connected to the output leads, and operation ends with zero potential across the output leads.

As shown in Fig. 3, the voltage output (curve 103) of the second thyratron 53 and the voltage output (curve 105) of the third thyratron reach high values alternately, as the third thyratron 49 and the second 53 respectively conduct except for negligible intervals during which the first thyratron is conductive. The current output of the second and third thyratrons 53 and 43 provides control voltages for the two grids 125 and 127 of a control tube 123 (Fig. 1*b*). Potential differences are impressed between the anodes 131 and 135 and the cathodes 129 of the control tube 123, through resistors 165 and 137, respectively, from a source 133 shown symbolically as a battery. When current is flowing through the second thyratron 53 in the multivibrator circuit, the second control tube grid 127 which is connected to the anode 47 of the second thyratron 53 of the multivibrator circuit becomes negative with respect to the cathode 129 of the control tube by the drop across resistor 45. This bias prevents current from flowing between the second anode 131 and the cathode 129 of the control tube. The first grid 125 of the control tube 123 which is connected to the anode 47 of the third thyratron 49 of the multivibrator circuit is at cathode potential. Current flows between the cathode 129 and the first anode 135 of the control tube 123 through resistor 137.

The negative terminal of the first resistor 137 of the control circuit is connected to the common return terminal 141 of the first secondary 143 of a three-phase transformer 145. The output line 149 of the first winding of this three-phase secondary leads to the grid 152 of the first thyratron 151 of the control circuit. Phase terminals 153 and 155 of the second and third windings of this secondary 143 lead to the grids 158 and 161 of the second and third thyratrons 157 and 159, respectively. Thus the potential across each winding of this three-phase secondary 143 in part determines the grid bias of one of the first three thyratrons 152, 161 and 163 of the control circuit. When current is flowing through the first resistor 137 of the control circuit, the potential difference across resistor 137 renders the grids 152, 158 and 161 of the thyratrons highly negative with respect to their cathodes, and the voltage in the first secondary 143 of the transformer 145 is insufficient to permit the three thyratrons 151, 157 and 159 to fire.

When the third thyratron 49 of the multivibrator circuit is rendered conductive, the potential difference between the cathode 129 and the first grid 125 of the control tube 123 is decreased so that current flow is blocked between the cathode 129 and the first anode 135 of the control tube 123. The second grid 127 of the control tube 123, now being at cathode potential of the control tube 123, permits current to flow between the cathode 129 and the second anode 131 of the control tube. The negative side of the second resistor 165 is connected to the neutral conductor 167 of the secondary 169 of the three-phase transformer 145. The phase terminals of the windings of the second secondary 169 are connected to the grids of the fourth, fifth and sixth thyratrons 171, 173 and 175, respectively, in the same manner as the phase terminals of the first secondary 143 were connected to the grids 152, 158, and 161 of the first three thyratrons. Analogously to the circumstances when the current flows in the first network including the first secondary 143 of the control transformer 145, current flow in the second network including the second secondary prevents the fourth, fifth and sixth thyratrons 171, 173, 175, respectively, from firing.

The anode 154 of the first thyratron 151 is connected through a capacitor 177, a peaking transformer 179 and one winding 181 of the third secondary 183 of the transformer 145 to the common line 139 joining the cathodes of the six thyratrons. The other five thyratrons are similarly connected through their separate capacitors, peaking transformers and windings of the third secondary 183.

Voltage of the proper polarity impressed through the output line 149 of the first winding of the first secondary 143 of the control transformer 145 will permit the first tube 152 to fire. While current is flowing in the second network causing the grids 152, 158 and 159 to be biased more positive, the voltage across the first winding 181 of the third secondary 183 of the control transformer 145 will, at some time, be of the proper magnitude relative to the cathode line 139 to provide the second and last requisite to allow the first thyratron 152 to fire. When the first thyratron 152 fires, it sends a pulse of current charging its capacitor which then discharges through the primary 180 of peaking transformer 179. While current is flowing in the second control network, the first three thyratrons 151, 157 and 159 fire in rotation, each thyratron sending a pulse through its capacitor to its peaking transformer 180.

When the first control circuit is conductive, the voltages in the second secondary 169 of the control transformer permit the fourth 171, fifth 173 and sixth 175 thyratrons to fire in sequence, each sending a pulse through the primary of its pulsing transformer.

The instantaneous presence of high voltage through a peaking transformer provides one condition that the corresponding ignitron become conductive. The other conditions that must be met before the respective thyratrons become conductive will be described with reference to Fig. 1*a*.

Associated with each ignitron is a thyratron which becomes conductive at a predetermined time thus starting current flow in the corresponding ignitron. The grid 185 of the first thyratron 187 is connected through a grid resistor 189, the secondary 182 of the peaking transformer 179, the secondary 190 of a firing transformer 191, a source of direct current, depicted in the drawing as a battery 193, to the common line 195 joining the cathodes 23 of the first three ignitrons 17, 19 and 21. The primary 192 of the first transformer 191 is connected in series with a first secondary winding 197 of a fourth three-phase secondary 225 of the control transformer 145.

In a similar manner the grids of the second and third thyratrons 184 and 186, respectively, are connected through their grid resistors, their peaking transformers, their firing transformers, the primary of which is connected in series with a corresponding phase winding of the fourth secondary 225 of the control transformer 145, and through a common supply battery 193 to the line 195 joining the cathodes of the first three ignitrons 17, 19 and 21.

A second transformer 201 is provided having three windings on a single core. Each of its three windings has between its terminals the potential difference that exists between the auxiliary anode and the cathode of the fourth, fifth, or sixth ignitron, 29, 31 and 33, respectively.

Thus, if the fourth, fifth or sixth ignitrons 29, 31, 33, respectively, is conductive and current can flow between the auxiliary anode 203 and the cathode 35 of any of these ignitrons, one of the windings of the second transformer 201 will be shorted causing a short to exist in the other two windings of this transformer 201.

The first winding 205 of the second transformer 201 is connected through dry rectifiers 207 to each of the firing transformers 191, 209, and 211 in the firing circuit of each of the first three ignitrons. The rectifiers 207 are connected so as to conduct electron current from the windings of transformer 201. A short across the latter windings in effect is a short across the primary of each firing transformer 191, 209 and 211. The rectifiers, on the other hand, block the flow of current from the firing transformers 191, 209, 211 associated with any ignitron through the firing circuit of another ignitron. If any winding of the second transformer 201 is shorted, it will cause a short circuit to exist in the primary of the firing transformer associated with each one of the grid circuits of the thyratrons which control the conductivity of their respective ignitrons. The circuit parameters are so arranged that the first ignitron 17 cannot become conductive unless its peaking transformer 179 is receiving a pulse voltage and its firing transformer 191 is impressing a voltage of the proper magnitude and polarity.

The circuit arrangement of the last three ignitrons 29, 31 and 33, differs from the circuit arrangement of the first three ignitrons 17, 19 and 21 because the anode 37 of the last three ignitrons is connected to a common line 195, whereas, the cathodes 23 of the first three ignitrons were connected to this common line.

The grid 213 of the thyratron 215 which controls the conductivity of the fourth ignitron 29 is connected through the peaking transformer 217, a biasing source of direct current, shown in the drawing as a battery 219, and a firing transformer secondary 222 to the cathode of the first thyratron 215. The primary 224 of the firing transformer 221 is connected in series with the fourth winding 223 of the fourth secondary 225 of the control transformer 145. The auxiliary anode 227 and the cathode 23 of each of the first three ignitrons 17, 19 and 21 is also connected across the primary of the firing transformer 221.

The following are simultaneous conditions which must be fulfilled before the fourth thyratron 215 will fire causing the fourth ignitron 29 to become conductive: the fourth peaking transformer 217 and the fourth firing transformer 221 must impress voltage of the proper polarity and proper magnitude to overcome the negative bias produced on a fourth control thyratron 215 by a battery 219. For the firing transformer 221 to impress a voltage of the proper magnitude, the following condition must be fulfilled. At the time chosen for the fourth ignitron 29 to fire, the sixth winding 223 of the fourth secondary 225 of the control transformer 145 must develop a high voltage of a proper polarity. If current is flowing in one of the ignitrons 17, 19 or 21, its auxiliary anode will conduct electron current from its cathode and the fourth firing transformer 221 will then be virtually short-circuited. Under such circumstances the ignitron 29 will fail to conduct. If the ignitrons 17, 19 and 21 are non-conductive and conditions for firing ignitron 29 are established, the latter will conduct.

The firing circuits of the fifth and sixth ignitrons 31 and 33 are similarly connected so that neither ignitron can be fired while any one of the first three ignitrons is conductive.

Dry rectifiers 228 are connected between one terminal of the primary of each of the firing transformers associated with the last three ignitrons and a common line 229 so that these transformers can receive energy from the control transformer 145 but can supply firing potential only in the firing thyratron circuit in which they are connected.

The current and voltage relationships and the conditions which must be met before each of the ignitrons fires can be more fully described with reference to the graphs in Figure 2(*a*), (*b*) and (*c*). In each of the three graphs time is plotted horizontally and voltage or current vertically. Points aligned vertically on the three graphs represent an identical instant. In Fig. 3(*a*) curves 230 represents the current flow through the welding transformer and curve 231 represents the source potential.

When current is being conducted to the welding transformer in one direction as in the left-hand ⅓ of the drawing, the voltage curve 231 is shown as being above the neutral axis, and in the second ⅓ of the drawing in which the welding transformer is receiving current of the opposite polarity, the voltage output of the ignitrons is shown as being below the neutral axis. Thus the output of the ignitrons is depicted as seen from the welding transformer. If the current and voltage were shown as seen from the power transformer, both the current and voltage output of the ignitron rectifiers would be graphed above the neutral axis. The present drawing takes cognizance of the circuits external to the rectifiers which cause the last three ignitrons to present a negative current to the welding transformer.

The voltage wave of the one phase 233 which is rectified by the first and fourth ignitrons 17 and 29 is drawn completely as seen from the power transformer. If the other two phases had been drawn completely in this manner, the drawings would have been unduly complicated. The center graph depicts the biasing voltage of the first thyratron 17. The lowest curve represents the square wave output of the multivibrator.

At the left-hand end of the curve in Fig. 2(a), the second ignitron 19 is represented as having just become conductive. When the voltage impressed across the third ignitron 21 exceeds the voltage impressed across the second ignitron, the third ignitron 21 fires. The first three ignitrons fire in sequence during the time interval represented by the left-hand ⅓ of curve 2(a). The current input (curve 230) to the welding transformer increases during this part of the cycle. While the current (curve 230) to the welding transformer 27 is flowing in one direction shown in Fig. 1a by a line above the neutral axis, the output of the multi-vibrator is of one polarity shown in curve c as being above its fictional neutral axis 235. When the polarity of the multivibrator output changes, no ignitron of the first three 17, 19 or 21 can become newly conductive. The ignitron which is conductive at this time continues conductive even after the voltage through it has become negative. This condition arises because the back E. M. F. produced by the decay of flux in the load counteracts the negative potential of the source and the net potential across the last ignitron to conduct continues positive. Thus, the ignitron acts as an inverter during this time, the current output of the welding transformer being supplied to the source and the flux in the transformer decaying to zero.

With the polarity of the multivibrator reversed the fourth, fifth or sixth ignitrons 29, 31 or 33, respectively, may become conductive in succession. One of them becomes conductive only after the last ignitron of the first group 17, 19, 21 becomes non-conductive. This newly conductive ignitron need not be selected by a selecting and timing system. Ignitrons 29, 31 and 33 cannot conduct so long as current flows to the auxiliary anode of one of the ignitrons 17, 19, 21, that is, so long as one of the latter is conductive. The current output of ignitrons 29, 31, 33 during this time is shown below the neutral axis 235 of Fig. 2(a) since the last three ignitrons are oppositely connected to the first three ignitrons. During the interval represented by the central ⅓ of the curve 2(a), the output current to the welding transformer increases in negative value. The last three ignitrons 29, 31 and 33 conduct current alternately until the output of the multivibrator changes polarity. The ignitron conductive as the multivibrator changes polarity acts as an inverter forcing the load current toward zero, and at the proper time the first three ignitrons 17, 19 and 21 become conductive alternately for a period of time.

Fig. 2b shows the biasing voltage of the thyratron which controls the conductivity of the first ignitron. The wave (curve 239) of varying amplitude represents the voltage impressed on the firing transformer 224 from the third winding 197 of the fourth secondary 225 of the control transformer 145. The magnitude of this voltage can reach a high maximum 241 only when none of the last three ignitrons 29, 31, or 33 is firing. The triangular peaks 243 represent the output of the peaking transformer 179 associated with the control circuit of the first ignitron 17. These peaks are impressed only when the multivibrator output is of the one polarity shown in the first ⅓ of the curve c. When the multivibrator output is of the other polarity the peaking transformers associated with the first three ignitrons emit no pulse. The upper line 245 of Fig. 2(b) represents the potential level that the grid 185 of the first thyratron 187 must reach before the first thyratron 187 can fire the first ignitron 17. As can be seen from the drawings, the voltage 244 required to fire the first ignitron is a combination of a peak 243 from the peaking transformer 179 and a high maximum 241 from the firing transformer 191. The low amplitude portion 251 of the curve 239 represents the condition which arises when one of ignitrons 29, 31 and 33 is conductive. Under such circumstances, the firing transformer in the grid circuit of the firing thyratron associated with the ignitron 17 is in effect short-circuited and the firing potential is too small to fire the thyratron. Similar curves could be presented for the other ignitron firing circuits.

Although I have shown and described a preferred embodiment of my invention, I realize that many modifications thereof are possible without departing from the spirit and scope of the invention. I do not intend, therefore, to limit my invention to the specific embodiment disclosed.

I claim as my invention:

1. In combination first terminals for deriving direct current, second terminals for supplying alternating current through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a control network connected to said second valve to control the conductivity of said second valve, interconnections between said first main valve and said control network for causing said control network to render conductive said second main valve during substantially all the time that said first main valve is non-conductive.

2. In combination first terminals for deriving direct current, second terminals for supplying alternating current through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a first control network connected to said first main valve to control the conductivity of said first main valve, a second main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second control network connected to said second valve to control the conductivity of said second valve, a third main valve, a third control network connected to said third valve to control the conductivity of said third main valve, a two-position switch in said third control network which in one position blocks said third main valve from becoming conductive and in the other position allows said third main valve to become conductive.

3. In combination first terminals for deriving electric power; second terminals for supplying power through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve, a third main valve, connected in circuit with said first terminals to conduct current therefrom to said second terminals, said second main valve being intitially conductive, a first control network having in circuit a first discharge valve which conducts current to said first control network to reach a stationary potential when said second main valve becomes conductive, said first control network being connected to said second main valve and said first main valve and adapted to render said first main valve conduc-

tive at the end of a predetermined interval of time after said second main valve becomes non-conductive, a second control network having in circuit a second discharge valve which causes said second control network to reach a stationary potential when said third main valve becomes conductive, said second control network being connected to said third main valve and said second main valve and adapted to render conductive said second main valve at the end of a predetermined interval of time after said third main valve becomes non-conductive, a third control network connected between said first main valve and said third main valve for causing said third main valve to become conductive at the end of a negligible interval of time after said first main valve becomes non-conductive, and interconnections between each two of the three said main valves so as to prevent the other two said main valves from conducting current when any one said main valve first becomes conductive.

4. In combination terminals for deriving direct current, second terminals for supplying power through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve, a third main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, said second main valve being initially conductive, a first control network having a two-position switch which in one of said positions prevents said third main valve from becoming conductive but in said second position, connecting said third main valve and said first main valve through a timing circuit, operates to render said third main valve conductive at the end of a negligible interval of time after said first main valve becomes non-conductive, a second control network connected to said third main valve and said second main valve so that at the end of the predetermined interval of time after said third main valve becomes non-conductive said second main valve becomes conductive, a third control network connected between said second main valve and said first main valve which causes said first main valve to become conductive at the end of a negligible interval of time after said second main valve becomes non-conductive, and interconnections between each two of the three said main valves which prevent the other two said main valves from conducting current when any one said main valve first becomes conductive.

5. In combination first terminals for deriving electric power, second terminals for supplying power through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve, a third main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, said second main valve being initially conductive, a first control network connected to said second main valve and said first main valve so that at the end of a predetermined interval of time after said second main valve becomes non-conductive said first main valve becomes conductive, a second control network connected to said third main valve and said second main valve so that at the end of a predetermined interval of time after said third main valve becomes non-conductive said second main valve becomes conductive, a third control network connected between said first main valve and said third main valve having a two-position switch which in one of said positions prevents said third main valve from becoming conductive but in said second position causes said third main valve to become conductive at the end of a negligible interval of time after said first main valve becomes non-conductive, a timing circuit adapted to cause said second main valve to become conductive at the end of a predetermined interval of time after said first main valve becomes conductive, a timing circuit adapted to cause said first main valve to become conductive at the end of a predetermined interval of time after said third main valve becomes conductive and connections between said first, second, and third main valves such that when any one of said main valves becomes conductive it renders non-conductive the main valve then conductive.

6. In combination first terminals for deriving electric power, second terminals for supplying power through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve, a third main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, said second main valve being initially conductive, a first control network connected to said second main valve and said first main valve so that at the end of a predetermined interval of time after said second main valve becomes non-conductive said first main valve becomes conductive, a second control network connected to said third main valve and said second main valve so that at the end of a predetermined interval of time after said third main valve becomes non-conductive said second main valve becomes conductive, a third control network connected between said first main valve and said third main valve having a two-position switch which in one of said positions prevents said third main valve from becoming conductive but in said second position causes said third main valve to become conductive at the end of a negligible interval of time after said first main valve becomes non-conductive and a capacitor in circuit with the more positive electrode of each two of the three said main valves connected to decrease the voltage difference across the other two said main valves preventing the other two said main valves from conducting current when any one of said main valves first becomes conductive.

7. In combination first terminals for deriving electric power, second terminals for supplying power through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve, a third main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, said second main valve being initially conductive, a first control network having in circuit a first discharge valve which causes said first control network to reach a stationary potential when said second main valve becomes conductive, said first control network being connected to said second main valve and said first main valve operating to render said first main valve conductive at the end of a predetermined interval of time after said second main valve becomes non-conductive, a second control network having in circuit a second discharge valve which causes said second control network to reach a stationary potential when said third main valve becomes conductive, said second con-

trol network being connected to said third main valve and said second main valve so that at the end of a predetermined interval of time after said third main valve becomes non-conductive said second main valve becomes conductive, a third control network connected between said first main valve and said third main valve having a two-position switch which in one of said positions prevents said third main valve from becoming conductive but in said second position causes said third main valve to become conductive at the end of a negligible interval of time after said first main valve becomes non-conductive, and a capacitor in circuit with the more positive electrode of each two of the three said main valves which decreases the voltage difference across the other two said main valves preventing the other two said main valves from conducting current when any one of said main valves first becomes conductive.

8. In combination first terminals for deriving electric current, second terminals for supplying alternating current through a load, a first main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a second main valve connected in circuit with said first terminals to conduct current therefrom to said second terminals, a control network connected to said second valve to control the conductivity of said second valve, an auxiliary control valve in said control network which conducts current when said first main valve is being rendered conductive so that said control network reaches a non-conductive steady state immediately after said second control network is rendered non-conductive, interconnections between said first main valve and said control network causing said control network to render conductive said second main valve during substantially all the time that said first main valve is non-conductive.

9. Apparatus for controlling the supply of power from an alternating current source through a load, comprising in combination a first main valve to be connected in circuit with said source to conduct current therefrom to said load, an auxiliary anode in said first main valve, a second main valve to be connected in circuit with said source to conduct current therefrom to said load, a control network connected to said second valve to control the conductivity of said second valve, and interconnections between said auxiliary anode and said control network causing said control network to control the conductivity of said second valve in dependence upon the current conducted by said auxiliary anode.

10. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first main valve to be connected in circuit with said source to conduct current therefrom to said load, an auxiliary anode in said first main valve, a second main valve to be connected in circuit with said source to conduct current therefrom to said load, a control network connected to said second valve to control the conductivity of said second valve, and interconnections between said auxiliary anode and said control network causing said control network to prevent current from flowing in said second valve so long as current is flowing through said auxiliary anode.

11. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first main valve to be connected in circuit with said source to conduct current therefrom to said load, an auxiliary anode in said first main valve, a first control network to control the conductivity of said first valve, a second main valve to be connected in circuit with said source to conduct current therefrom to said load, a second control network connected to said second valve to control the conductivity of said second valve, a control system for said networks operating to cause said first network to render said first valve conductive for a predetermined time interval and thereafter to permit said first valve to become non-conductive and connections between said first network and said second network to cause said second network to restrain said second valve from becoming conductive during said predetermined interval and thereafter allows said second network to permit said second valve to become conductive, and interconnections between said auxiliary anode and said control network causing said control network to restrain current from flowing is said second valve so long as current is flowing through said auxiliary anode.

12. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first main valve to be connected in circuit with said source to conduct current therefrom to said load, an auxiliary anode in said first main valve, a first control network to control the conductivity of said first valve, a second main valve to be connected in circuit with said source to conduct current therefrom to said load, an auxiliary anode in said second main valve, a second control network connected to said second valve to control the conductivity of said second valve, a control system for said networks operating to cause said network to render said valves conductive alternately for predetermined intervals of time, interconnections between said auxiliary anode and said control network causing said control network to restrain current from flowing in said second valve so long as current is flowing through said last named auxiliary anode, and connections between said auxiliary anode of said second valve and said first network for causing said first network to restrain current from flowing in said first valve so long as current is flowing through said last-named auxiliary anode.

13. Apparatus for controlling the supply of current from a polyphase alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, an auxiliary anode in each valve of said first plurality of valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, a control network connected to said second plurality of valves to control the conductivity of said second plurality of valves, and interconnections between said auxiliary anodes and said control network causing said control network to control the conductivity of said second plurality of valves in dependence on current conducted by said auxiliary anodes in any valve of said first plurality of valves.

14. Apparatus for controlling the supply of current from a polyphase alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, an auxiliary anode in each valve of said first plurality of

valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, an auxiliary anode in each valve of said second plurality of valves, a control network connected to an auxiliary anode in each valve of said second plurality of valves to control the conductivity of said first plurality of valves, and interconnections between said first auxiliary anodes and said control network causing said control network to control the conductivity of said second plurality of valves in dependence on current conducted by said first auxiliary anodes in any valve of said first plurality of valves.

15. Apparatus for controlling the supply of current from a polyphase alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, a first auxiliary anode in each valve of said first plurality of valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, a second auxiliary anode in each valve of said first plurality of valves, a block network connected to an auxiliary anode in each valve of said second plurality of valves to block the conductivity of said second plurality of valves, and interconnections between said second auxiliary anodes and said control network causing said block network to control the conductivity of said first plurality of valves during the time that current flows to said second auxiliary anodes.

16. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, a first auxiliary anode in each valve of said first plurality of valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, an auxiliary anode in each valve of said second plurality of valves, a first transformer having one winding connected in circuit with each of said second auxiliary anodes, so that one winding of said first transformer is shorted when current is flowing to any one of said second auxiliary anodes, a second transformer connected to each one of the first plurality of valves so as to control the conductivity of said first plurality of valves and so as to block conductivity of said first plurality of valves when said second transformers are shorted, said second transformers being connected to one winding of said first transformer so that each of said second transformers is short-circuited when current flow to any one of said second auxiliary anodes shorts the windings of said second transformer.

17. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, a first auxiliary anode in each valve of said first plurality of valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, a second auxiliary anode in each valve of said second plurality of valves, a first transformer having one winding connected in circuit with each of said second auxiliary anodes so that one winding of said first transformer is shorted when current is flowing to any one of said second auxiliary anodes, a second transformer connected to each one of the first plurality of valves so as to control the conductivity of said first plurality of valves and so as to block conductivity of said first plurality of valves when said second transformer is shorted, said second transformers being connected to one winding of said first transformer so that each of said second transformers is short-circuited when current flow to any one of said second auxiliary anodes shorts the windings of said second transformer, and connections between said second transformers and each of said first auxiliary anodes so that current flow to each of said first auxiliary anodes shorts each of said second transformers.

18. Apparatus for controlling the supply of current from an alternating current source through a load, comprising in combination a first plurality of valves to be connected in circuit with said source to conduct current of one polarity therefrom to said load, a first auxiliary anode in each valve of said first plurality of valves, a second plurality of valves to be connected in circuit with said source to conduct current of the other polarity therefrom to said load, a second auxiliary anode in each valve of said second plurality of valves, a first transformer having one winding connected in circuit with each of said second auxiliary anodes so that one winding of said first transformer is shorted when current is flowing to any one of said second auxiliary anodes, a second transformer connected to each one of the first plurality of valves to control the conductivity of said first plurality of valves and to block conductivity of said first plurality of valves when said second transformer is shorted, said second transformers being connected to one winding of said first transformer so that each of said second transformers is short-circuited when current flow to any one of said second auxiliary anodes shorts the windings of said second transformer, connections between said second transformers and each of said first auxiliary anodes so that current flow to each of said first auxiliary anodes shorts each of said second transformers, a first plurality of rectifiers in circuit with the first auxiliary anodes and said second transformer windings so that current flowing to any of the first auxiliary anodes cannot short the second transformer windings, and a second plurality of rectifiers in circuit with the second auxiliary anodes and said second transformer windings so that current flowing in any of the second auxiliary anodes cannot short the first transformer windings.

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