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CONTROL SYSTEM

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Fig. 1.

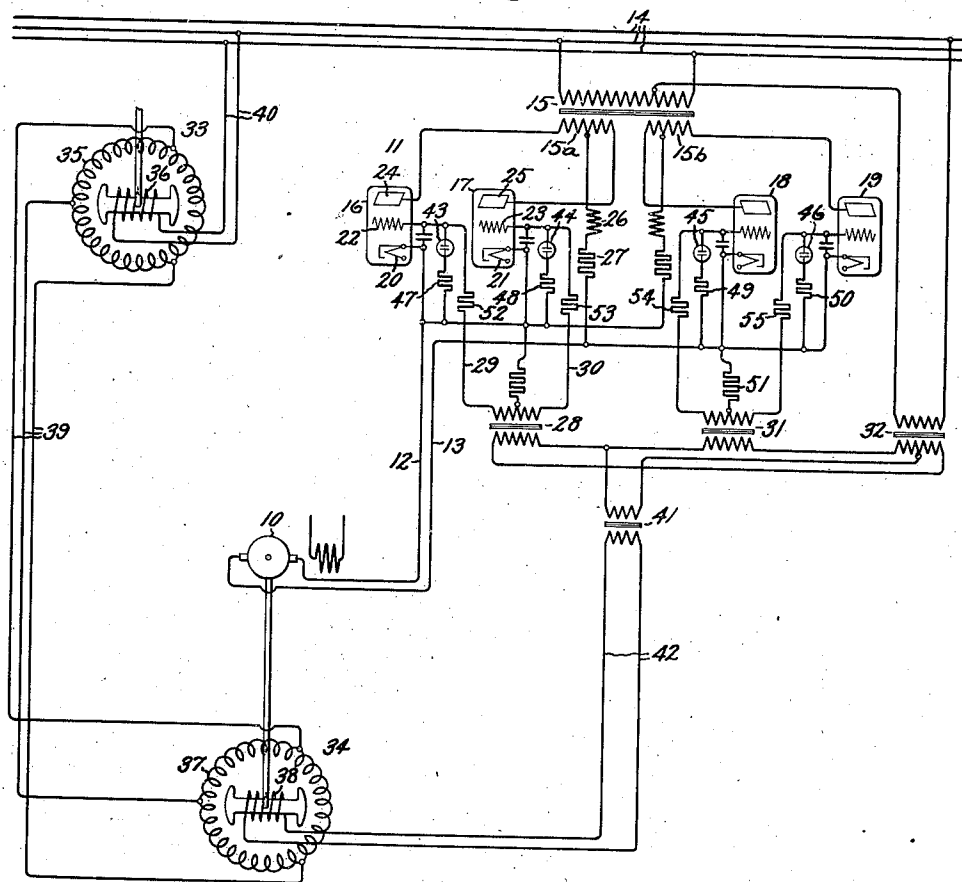
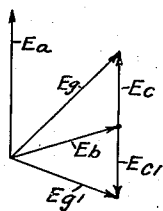


Fig. 2.



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CONTROL SYSTEM

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9 Claims. (Cl. 250—27)

This invention relates to control systems, more particularly to systems in which a translating circuit is supplied from electric valve apparatus, and an object of the invention is the provision of a simple reliable, efficient and improved system of this character.

More specifically the invention relates to control systems in which at least two electric valves are utilized to supply current in opposite directions to a translating circuit. In systems of this character, voltage is supplied to grids of the valves in such a manner that a positive voltage is applied to the grid of one valve so as to actuate that valve to supply current to the translating circuit in one direction and a negative voltage is applied to the second valve to render the second valve inactive; and means are provided for reversing the polarities of the grid voltages thereby deenergizing the active valve and energizing the inactive valve to supply current to the translating circuit in the reverse direction. Within certain limits an electric valve is non-conducting when a negative voltage is applied to the grid. It has been determined, however, that if the negative voltage on the grid of the valve is increased beyond a predetermined critical value, the valve will break down and become conducting. This is especially true of valves of the vapor electric type. It has happened that with valves connected to supply current to a circuit in opposite directions, an increase in the positive grid voltage of the active valve to increase the current supplied to the load circuit resulted in increasing the negative voltage of the inactive valve beyond this critical value, thereby causing the inactive valve to break down and become conducting, with the result that both valves supplied currents to the circuit in opposite directions at the same instant which interfered with the proper operation of the system. Accordingly a more specific object of this invention is the provision of an improved system in which this disadvantage is eliminated.

In carrying the invention into effect in one form thereof, at least two electric valves are provided for supplying current in respectively opposite directions to the load circuit and means are provided for supplying voltage to the grids of these valves in such a manner that a positive voltage is applied to the grid of one valve to energize that valve and a negative voltage is applied to the grid of the second valve to render the second valve inactive together with means for limiting the negative grid voltage of the inactive valve to a predetermined value to prevent ener-

gization of the inactive valve. In one form of the invention a discharge device such as an electric glow lamp is connected between the cathodes and grids of each of the valves. In another form of the invention, a non-linear resistance is connected between the cathodes and grids.

In illustrating the invention in one form thereof it is shown as embodied in a follow-up system, in which a load body is driven into positional agreement with a pilot device by means of an electric motor supplied from electric valve apparatus.

For a better and more complete understanding of the invention reference should now be had to the following specification and to the accompanying drawing in which Fig. 1 is a simple, diagrammatic illustration of an embodiment of the invention and Fig. 2 is a vector diagram of certain electrical operating characteristics of the system of Fig. 1 facilitating the understanding of the invention.

Referring now to the drawing a suitable translating circuit including the direct current electric motor 10 is supplied with direct current in respectively opposite directions by means of the electric valve apparatus 11 to the output circuit of which the armature terminals of the motor 10 are connected by means of the conductors 12 and 13. The electric valve apparatus 11 is itself supplied from any suitable source such for example as the three phase supply source represented by the three supply lines 14 by means of a suitable supply transformer 15, the terminals of the primary winding of which are connected to the middle and lower supply line 14 as illustrated. As shown the electric valve apparatus 11 comprises a pair of electric valves 16, 17 connected for full wave rectification for supplying direct current in one direction to the armature of the electric motor 10 and a similar pair of electric valves 18, 19 also connected for full wave rectification to supply direct current to the armature of the motor 10 in the reverse direction.

The electric valves 16, 17, 18 and 19 are preferably of the three electrode type and as shown the valves 16, 17 are respectively provided with cathodes 20 and 21, grids 22 and 23, and plates or anodes 24 and 25. The pair of valves 18 and 19 have similar elements as illustrated. These valves are preferably of the vapor electric type, i. e., after exhaust the envelopes are filled with a suitable inert gas such for example as mercury vapor, the presence of which within the envelope serves to convert the usual pure electron discharge into an arc stream thus constituting the

valves electrostatically or grid controlled arc rectifiers.

The plates 24, 25 of the valves 16 and 17 are respectively connected to the opposite terminals of the secondary winding portion 15_a of the transformer 15, the mid-point of which winding portion is connected to the conductor 13 through a suitable smoothing reactance 26 and a current limiting resistance 27 connected in series relationship with each other and the cathodes 20 and 21 of this pair of electric valves are directly connected to the conductor 12. Current flows in the plate circuit of the electric valves only during that half cycle of the voltage applied to the anode in which the potential of the anode is positive with respect to that of the cathode and this flow of current is initiated by supplying to the control grids a voltage that is more positive with respect to the anode voltage than a predetermined critical value. By varying the point in the cycle of the anode voltage at which the grid voltage becomes sufficiently positive to initiate current flow in the anode circuit, the average value of the current flowing in the latter circuit is controlled as desired and it will thus be seen that if an alternating voltage is supplied to the control grid of the electric valve apparatus, the point in the cycle of applied anode voltage at which the grid becomes sufficiently positive to initiate current flow in the anode circuit may be varied by shifting the phase of the grid voltage with respect to that of the anode voltage.

As shown in the drawing, alternating voltage is supplied to the grids 22, 23 of the electric valves 16 and 17 by means of a suitable grid transformer 28, the opposite terminals of the secondary winding of which are respectively connected to the grids 22 and 23 by means of conductors 29 and 30 and alternating voltage is likewise supplied to the grids of the electric valves 18 and 19 by means of the grid transformer 31. The primary windings of the grid transformers 28 and 31 are connected in series relationship with each other and are in turn connected to the terminals of the secondary winding of a grid bias transformer 32, one terminal of the primary winding of which is connected to the upper supply line 14 and the opposite terminal of which is connected to an intermediate point on the primary winding of the power supply transformer 15.

The connection of one terminal of the primary winding of the grid supply transformer 32 to an intermediate point of the power supply transformer 15 serves to shift the phase of the grid bias voltage with respect to that of the anode voltage as illustrated in the vector diagram of Fig. 2 in which the vector E_a represents the voltage supplied to the anodes and the vector E_b represents the grid bias voltage supplied to the grids.

The phase relationship of the voltages applied to the grids and anodes of the electric valves is illustrated by the angle between the vectors E_a and E_b . When the grid voltage is in phase with the anode voltage, maximum current is delivered in the output circuit of the electric valve and when the grid voltage is 90° out of phase with the anode voltage, substantially no current flows in the output circuit. For intermediate phase relationships of the grid and anode voltage, the current flow in the output circuit is proportionate to the phase relationship. The phase relationship between the grid and anode voltages is controlled by any suitable means such for example as the electrical motion transmitting device 33 and a receiving device 34 connected between the

supply source 14 and the circuits for applying voltage to the grids of the electric valve apparatus. The transmitting device has a stator member provided with a polycircuit stator winding 35 which is physically similar to the three phase winding of an alternating current dynamo electric machine and is also provided with a rotor member having a single phase rotor winding 36 arranged in inductive relationship with the stator winding 35.

The receiving device 34 is provided with a stator winding 37 and a single phase rotor winding 38 which are in all respects identical with the corresponding windings of the transmitting device 33. As shown three equi-spaced stator winding terminals of the transmitting device 33 are connected to three corresponding stator winding terminals of the receiving device 34 by means of the three conductors 39. The alternating voltage is supplied to the rotor winding 36 of the transmitting device from the source 14 to the middle and lower supply lines of which the winding 36 is connected by means of conductors 40. The current flowing in the rotor winding 36 sets up an alternating magnetic field, the position of which in space with respect to the stator winding 35 depends upon the position of the rotor winding 36 with respect to a predetermined axis of the stator winding 35. This alternating magnetic field induces alternating voltages in the circuits of stator winding 35 which in turn establish current flow in the stator winding 37 of the receiving device 34. The currents flowing in the circuits of the stator winding 37 reproduce the magnetic field of the transmitting device with the result that a voltage is induced in the rotor winding 38 of the receiving device, the magnitude of which depends upon the relative position of an axis of the rotor winding with respect to the axis of the magnetic field of the stator winding. The voltage thus induced in the rotor winding 38 of the receiving device is supplied to the grid circuit of the electric valve apparatus 11 by means of a step-up transformer 41, the terminals of the secondary winding of which are respectively connected to the rotor winding 38 by means of conductors 42 and the opposite terminals of the secondary winding of which are respectively connected to a mid-point of the secondary winding of the grid bias transformer 32 and to a point between the primary windings of the individual grid transformers 28 and 31. Since the rotor winding 36 of the transmitting device is connected to the same phase of the supply source as that from which the anodes of the electric valve apparatus are supplied the component of voltage supplied to the grid circuit of the electric valve apparatus from the receiving device 34 is substantially in phase with the anode voltage as represented in Fig. 2 of the drawing by the vector E_c for the pair of tubes 16, 17; the vector E_c shown substantially in phase with the vector E_a representing the anode voltage. The corresponding component voltage for the other pair of valves is represented by the vector E_{c1} , substantially 180° out of phase with the vector E_c . It will thus be seen that the resultant voltage supplied to the grids of the electric valve apparatus is made up of the two components E_b and E_c for the pair of valves 16, 17, and is represented by the vector E_g and the resultant grid voltage for the pair of valves 18, 19 is made up of the two components E_b and E_{c1} , and is represented by the vector E_{g1} . This diagram holds only for the condition of the system being out

of correspondence in one direction. If the system is out of correspondence in the opposite direction, the vectors E_c and E_{c1} and the voltages which they represent are reversed. When the axis of the rotor winding 38 is at right angles with the axis of the magnetic field of the stator winding 37 of the receiving device, the voltage induced in the rotor winding 38 is substantially zero and consequently the component of voltage supplied to the grid of the electric valve apparatus from the rotor winding 38 and represented by the vectors E_c and E_{c1} is substantially zero, as a result of which the vectors E_g and E_{g1} coincide with the vector E_b ; that is to say, the voltage actually applied to the grid is the grid bias voltage supplied from the source 14 through the grid bias transformer 32. When the grid and anode voltages are substantially 90° out of phase as represented by the phase relationship of the vectors E_a and E_b the current flow in the output circuit of the electric valve apparatus is minimum or substantially zero. When the axis of the rotor winding 38 is substantially parallel with the axis of the magnetic field of the stator winding 37 of the receiving device, the voltage induced in the rotor winding 38 is maximum with the result that the magnitude of the vectors E_c and E_{c1} is correspondingly increased. As the magnitude of vectors E_c and E_{c1} increases, the vector E_g which represents the actual or resultant voltage applied to the grid is shifted closer to the in-phase relationship with the anode voltage for the pair of valves 16, 17 represented by the vector E_a and the flow of current in the output circuit of the electric valve apparatus is correspondingly increased. For the other pair of valves the vector E_{g1} is shifted further out of phase with the anode voltage.

It will be clear that when the polarity of the voltage represented by the vector E_c applied to the grids 22 and 23 of the electric valves 16 and 17 is positive the polarity of the voltage applied to the grids of the electric valves 18, 19 will be negative, with the result that the valves 16, 17 supply current to the translating circuit 10, 12, 13 in a predetermined direction and the valves 18, 19 are inactive. For the purpose of providing a high degree of accuracy in the follow-up system the transformer 41 is so designed that when the rotor of the receiving device 34 is but slightly out of correspondence with the rotor of the transmitting device 33, e. g. 1°, the component of voltage represented by the vector E_c will be a very substantial amount and sufficient in magnitude to advance the phase of the grid voltage represented by the vector E_g with respect to the anode voltage E_a so one pair of electric valves will become active and supply current in the output circuit to the driving motor 10. Consequently when the rotor of the receiving device 34 is out of correspondence with the rotor of the transmitting device 33 by a large amount, the component of voltage supplied to the grid circuit from the rotor winding 38 is correspondingly increased. The magnitude of this voltage is increased to such an extent that the negative voltage applied to the grid of the inactive pair of electric valves exceeds the predetermined critical value which causes this pair of tubes to break down and become conducting with the result that both pairs of tubes attempt to supply current to the translating circuit in opposite directions at the same time, thereby interfering with the proper operation of the system.

As far as is now known, this undesirable condition may be due to either, or a combination of two phenomena; one known as "grid emission" and the other known as "cold cathode discharge". In explaining the phenomenon of grid emission it is pointed out that the cathodes 20, 21, etc. of the valves are usually coated with an electron emitting oxide. During the usual operation of the valve some of this oxide may be and often is deposited on the grid by the arc stream. When the control object 33 and the controlled object 34 become out of correspondence by a large amount, it is possible, in the system illustrated, for the grid to become as much as 1100 volts negative with respect to the cathode which in turn may at the same time become as much as 1200 volts negative with respect to the anode. In other words, the grid may become as much as 2300 volts negative with respect to the anode. This voltage, together with the oxide deposited on the grid, causes the grid to become a cathode and initiate a discharge between itself and the anode, which discharge though small is sufficient to ionize the space between the cathode and anode and initiate the discharge between the cathode and anode.

The phenomenon of "cold cathode discharge" takes place between the grid and cathode. It is pointed out above that at times the grid may become as much as 1200 volts negative with respect to the cathode, or vice versa, the cathode become 1200 volts positive with respect to the grid. This causes the cathode to become an anode and the grid to become a "cold cathode" thereby initiating a discharge between the two which is sufficient to ionize the tube and to start the regular discharge between the cathode and anode. The above conditions are often further aggravated by a grid structure having many sharp points.

In order to limit the magnitude of the negative voltage applied to the grids of the electric valves 16, 17, 18 and 19 to a permissible value, electric glow discharge lamps 43, 44, 45 and 46 are respectively connected between the grids and cathodes of corresponding electric valves 16, 17, 18 and 19, and suitable resistance devices 47, 48, 49 and 50 are respectively included in the connection in series relationship with the corresponding electric discharge lamps 43, 44, 45 and 46, also resistances 52 and 53 are included in circuit between the terminals of the secondary winding of the grid transformer 28 and the grids 22 and 23 and similar resistances 54 and 55 are included in circuit between the secondary of transformer 31 and the grids of valves 18 and 19. A glow discharge lamp comprises a pair of spaced electrodes within an envelope which is filled with a suitable gas such for example as neon. As long as the voltage, applied to the electrodes of a glow lamp, is below a certain critical value no discharge takes place between the electrodes whereas when this critical value is reached the gas is ionized and a discharge takes place across the space between the electrodes.

Instead of the glow lamp illustrated in the drawing, a suitable non-linear resistance device may be employed and connected between the grids and cathodes of the electric valve. A non-linear resistance is a resistance, the conductance of which varies with some power of the impressed voltage other than unity. Although any suitable non-linear resistance may be employed it is preferred to utilize a resistance composed of silicon

carbide crystals held together by a suitable binder such for example as disclosed in U. S. Patent No. 1,822,742—McEachron, dated September 3, 1931. When a low voltage is impressed upon a non-linear resistance of this character, a very negligible current flows through the resistance. However, when the impressed voltage is increased beyond a predetermined critical value, the current increases rapidly. Thus when non-linear resistances of this character are utilized in place of the glow lamps the resultant effect in the circuit is substantially the same; that is to say, when the voltage is below a certain critical value substantially no current flows through the resistance and when the impressed voltage exceeds this critical value a very large current flows through the resistance.

With the above understanding of the apparatus and its organization in the completed system the operation of the system itself will readily be understood from the detailed description which follows:

Assuming the rotors of the transmitting and receiving devices 33 and 34 to be in exact correspondence, the axis of the rotor winding 38 of the receiving device is at right angles with the magnetic field of the stator winding and no voltage is induced in the rotor winding 38 as a result of which the phase relationship between the voltages applied to the grids and anodes of the electric valve apparatus is as represented by the vectors E_a and E_b , and both pairs of electric valves 16, 17 and 18, 19 are non-conducting and the system is at rest. If the rotor of the transmitting device 33 is rotated the magnetic field of the stator winding 37 of the receiving device is no longer at right angles with the rotor winding 38 and a voltage is induced in the rotor winding and applied to the grids of the electric valve apparatus, as represented by the vectors E_c and E_d , thereby shifting the phase relationship of the resultant grid voltage with respect to the anode voltage represented by the vector E_a . Thus one pair of electric valves becomes conducting and supplies current to the electric motor 10 in such a direction as to cause the motor 10 to drive the rotor of the transmitting device in a direction to reestablish correspondence between the rotors of the transmitting and receiving devices. As the phase of the grid voltage is advanced with respect to the anode voltages of the valves 16, 17 it is retarded with respect to the anode voltages of the valves 18, 19 with the result that this pair of valves remains inactive due to the fact that when the grid voltage of one of the valves 16, 17 is positive the grid voltage of the corresponding valve 18 or 19 is negative.

If the rotors of the transmitting and receiving devices 33 and 34 become out of correspondence with each other by a large amount, the components of voltage E_c and E_d supplied to the grids of the electric valve apparatus become greatly increased and is further multiplied due to the transformation effected by the transformer 41, with the result that the magnitude of the negative voltage supplied to the grids of the valves 18, 19 exceeds the critical value at which the valves 18 and 19 would become conducting and attempt to supply current to the motor 10 in a direction opposite to that in which current is being supplied by the pair of electric valves 16, 17. However, the critical value of breakdown voltage of the electric glow lamps 45, 46 is reached before the critical value of negative

grid voltage with the result that the glow lamps 45, 46 break down and become conducting. The establishment of current flow through the electric glow lamps 45 and 46 results in increasing the voltage drop across the resistances 54 and 55 as well as increasing the voltage drop across the resistance 51 connected between the mid-points of the secondary winding of the grid transformer 31 and the cathode of the electric valves 18 and 19 with the result that the negative grid voltage is prevented from exceeding the critical value at which the valves 18 and 19 become conducting.

If the impedance in transmitting device 33, receiving device 34 and transformer 41 is of a magnitude sufficient to cause a large enough drop in the voltage output of transformer 41 when the additional load taken by the glow lamps is added so as not to cause the negative grid voltage to exceed the critical value, the resistances 52, 53, 54 and 55 may be omitted.

Rotation of the rotor of the transmitting device 33 in the opposite direction from that assumed in the above discussion results in applying positive voltage to the grids of the valves 18 and 19 so that these valves become conducting and supply current to the motor 10 in a direction such that the motor 10 rotates the rotor member of the receiving device 34 in a direction to reestablish correspondence, and a negative voltage is applied to the grids 22, 23 of the electric valves 16 and 17 so as to maintain this pair of valves in a deenergized condition. If the rotors of the transmitting and receiving devices are out of correspondence by a large amount the electric glow lamps 43 and 44 prevent the negative voltages of grids 22 and 23 from exceeding the critical value at which the valves 16 and 17 would be conducting in exactly the same manner as that described in connection with the pair of valves 18 and 19.

When non-linear resistances are utilized in place of the electric glow lamps 43, 44, 45 and 46 the operation to prevent excessive negative grid voltage is exactly the same as that described in connection with the use of the glow lamps.

Although in accordance with the provisions of the patent statutes, this invention is described in concrete form, it will be understood that the apparatus and connections described and shown in the drawing are merely illustrative and that the invention is not limited thereto since alterations and modifications will readily suggest themselves to persons skilled in the art without departing from the true spirit of the invention or the scope of the annexed claims.

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

1. A control system comprising a translating circuit, supply means for said circuit comprising a plurality of electric valves each provided with a cathode and a control grid, means for supplying a positive voltage to the grid of one of said valves and a negative voltage to the grid of another of said valves, and means for limiting said negative voltage to a predetermined value.

2. A control system comprising a translating circuit, supply means for said circuit comprising at least two electric valves each having a cathode and a control grid and connected to supply current to said circuit in respectively opposite directions, means for supplying a positive voltage to the grid of one of said valves to render said valve active and a negative voltage to the grid

of a second valve for rendering said second valve inactive, and a device connected between the cathode and grid of each of said valves to prevent said negative voltage activating the inactive valve.

3. A control system comprising a translating circuit, supply means for said circuit comprising at least two electric valves, each provided with a cathode and a control grid and connected to supply current to said circuit in respectively opposite directions, means for supplying an alternating voltage to said grids so that an instantaneous positive voltage is applied to the grid of one of said valves to energize said valve and an instantaneous negative voltage is applied to the grid of a second valve to render said second valve inactive, and a device connected between the grid and cathode of each of said valves for preventing said negative voltage attaining a value sufficient to energize said inactive valve.

4. A control system comprising a translating circuit, supply means for said circuit comprising at least two electric valves each provided with a cathode and a control grid and connected to supply current to said circuit in respectively opposite directions, means for supplying an alternating voltage to said grids so that a positive voltage is applied to the grid of one of said valves to energize said valve and a negative voltage to a second of said valves to render said second valve inactive, means for reversing the polarity of said voltages and a device connected between the cathode and grid of each of said valves for limiting said negative voltage to a predetermined value and thereby prevent said negative voltage from energizing the inactive valve.

5. A control system comprising a translating circuit, supply means for said circuit comprising at least two electric valves each having a cathode and a control grid and connected for supplying current to said circuit in respectively opposite directions, means for supplying an alternating voltage to said grids so that a positive voltage is applied to the grid of one of said valves to energize said valve and a negative voltage is applied to the grid of a second of said valves to render said valve deenergized, means for varying said alternating voltage, and a device connected between the cathode and grid of said valves for limiting said negative voltage to a predetermined value to prevent energization of said second valve.

6. A control system comprising a load circuit, supply means for said circuit comprising at least two vapor electric valves each having a cathode and a control grid and connected to said circuit for supplying current thereto in respectively opposite directions, means for supplying a positive voltage to the grid of one of said valves to energize

said valve and a negative voltage to the grid of a second valve to render said second valve inactive, and an electric glow discharge device connected between the grid and cathode of each of said valves for limiting said negative voltage to a predetermined value to prevent energization of the inactive valve.

7. A control system comprising a load circuit, supply means for said circuit comprising at least two vapor electric valves each provided with a cathode and a control grid and connected for supplying current to said circuit in respectively opposite directions, means for supplying an alternating voltage to said grids so that a positive voltage is applied to the grid of one of said valves to energize said valve and a negative voltage is applied to the grid of a second valve to maintain said second valve inactive, means for reversing the polarity of the voltages applied to said grids so as to energize the inactive valve and deenergize the active valve, means for increasing said alternating voltage, and an electric glow discharge device connected between the grid and cathode of each of said valves for limiting the negative voltage to a predetermined value to prevent energization of the inactive valve.

8. A control system comprising a load circuit, supply means for said circuit comprising at least two electric valves each provided with a cathode and a control grid and connected to said circuit so as to supply current thereto in respectively opposite directions, means for supplying a voltage to the grids of said valves so that a positive voltage is applied to the grid of one valve to energize said valve and a negative voltage is applied to the grid of a second valve to render said second valve inactive and a non-linear resistance device connected between the cathode and grid of each of said valves for limiting said negative voltage to a predetermined value to prevent energization of the inactive valve.

9. A control system comprising a load circuit, supply means for said circuit comprising at least two vapor electric valves each having a cathode and a control grid connected to supply current to said circuit in respectively opposite directions, means for supplying an alternating voltage to said grids so that a positive voltage is applied to the grid of one of said valves to energize said valve and a negative voltage is applied to the grid of a second valve to render said second valve inactive, means for reversing the polarities of said grid voltages to energize the inactive valve and deenergize the active valve, means for increasing said alternating voltage and a non-linear resistance device connected between the cathode and grid of each of said valves for limiting said negative voltage to a predetermined value to prevent energization of the inactive valve.

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