May 21, 1935. P. H. CRAIG 2,001,838

POWER CONTROL CIRCUITS

Filed Sept. 5, 1933

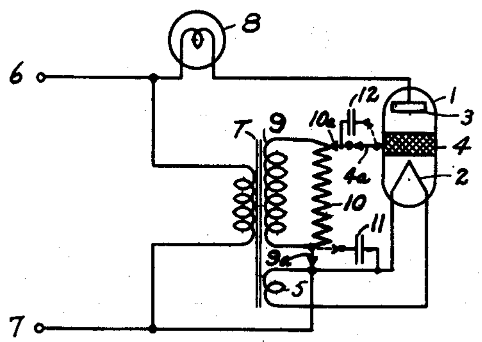

FIG. 1

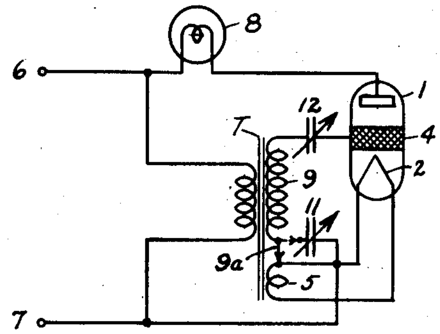

FIG. 2

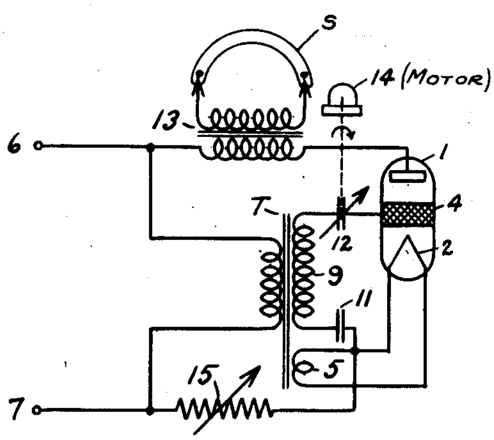

FIG. 3

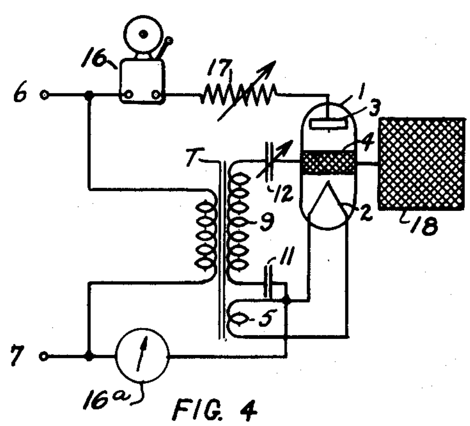

FIG. 4

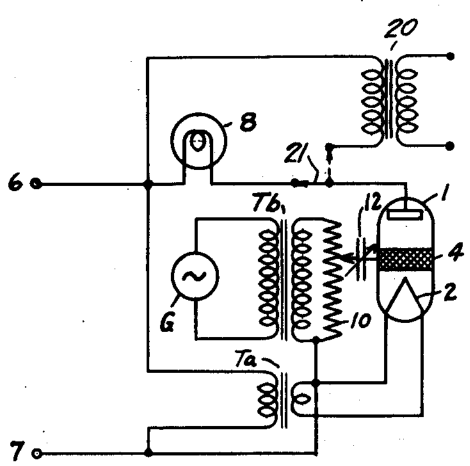

FIG. 5

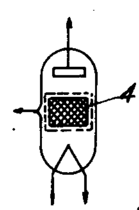

FIG. 6

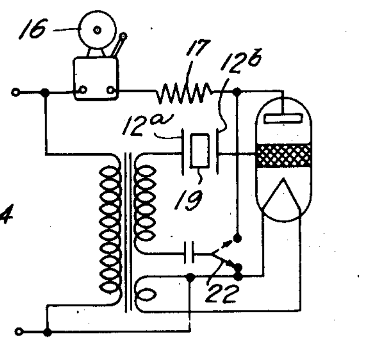

FIG. 4a

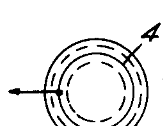

FIG. 7

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Patented May 21, 1935 2,001,838

UNITED STATES PATENT OFFICE

2,001,838

POWER CONTROL CIRCUITS

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Application September 5, 1933, Serial No. 688,249

15 Claims. (Cl. 250—27)

This invention relates to circuit arrangements for the control of electric currents of substantial magnitude.

An object of the invention is to devise relay circuits for the control of relatively large currents in response to voltage variations applied to the input circuit of the relay.

A further object is to devise a voltage operated relay circuit for the control of relatively large currents by simple means devoid of movable or sliding contacts.

My invention involves the use of a gaseous relay tube having an electron emitting cathode, an anode and a grid or control electrode. Such gaseous or vapor relays have been used in prior arrangements for the control of relatively large currents. In one form of gaseous relay the control element is located within the envelope or tube in the space between the cathode and the anode, and in another form, the control or grid element is located outside of the envelope, usually at a point lying between the cathode and the anode. My invention involves the use of the second form of gaseous relay, that is, the type with the external grid.

It is known that for either form of relay, when a circuit is completed between the cathode and the anode including a source of current, the arc between the anode and the cathode may be prevented from starting by applying a negative potential to the control electrode. Once the arc starts, however, the anode current cannot be interrupted by control of the grid potential, but can only be interrupted by removing the anode potential or by interrupting the circuit. By supplying the anode circuit with alternating current, the arc is established during each pulsation when the anode is positive with respect to the cathode and is automatically extinguished at the end of each positive pulsation. An arrangement has been proposed for preventing or permitting the flow of alternating current in the anode circuit of the relay by applying to the control electrode a variable direct current having a negative polarity with respect to the cathode. It has also been proposed to control the amount of alternating current flowing in the anode circuit by applying to the control electrode an alternating voltage of variable phase relation, such that the starting of the arc within the tube may be made to occur at different points in the cycle of the alternating current. In the arrangement which I have devised, control of the alternating current flowing in the anode circuit is obtained by applying to the grid of the tube an alternating current voltage of fixed phase and variable amplitude. As indicated above, the grid is located on the outside of the tube and is preferably galvanically insulated from the anode and cathode elements.

In my copending application Ser. No. 577,691 I have shown a control circuit of the same general type as the present invention wherein a progressive variation of the anode current is obtained by applying to the grid an alternating current of variable amplitude but having a fixed lagging phase displacement with respect to the anode voltage of the order of 135 degrees. This circuit requires special phase determining impedances, but in the circuits of the present invention, it is possible to utilize a control voltage of opposite phase with respect to the anode voltage, and special phase determining impedances are not required.

My invention is illustrated in the accompanying drawing in which:

Figure 1 is a circuit diagram of one form of my invention;

Figure 2 is a circuit diagram of a modified form of control circuit;

Figure 3 is a diagram of a control circuit employed for flashing a neon sign;

Figure 4 is a diagram of a circuit employed as a burglar alarm;

Figure 4*a* is a modification of the circuit shown in Figure 4.

Figure 5 is a diagram of a circuit in which separate alternating current sources are connected to the anode-cathode and control electrode circuits.

Figure 6 illustrates a modified tube construction using an internal grid; and

Figure 7 is a plan view of Figure 6.

Referring to Figure 1, relay tube **1** is formed of a glass bulb provided with an electron emitting cathode **2**, an anode **3**, and an external grid or control electrode **4**. The tube **1** is also provided with a gaseous atmosphere such as mercury vapor, or other suitable ionizable gas or vapor. The relay tube may consist of a type 866 hot-cathode mercury vapor rectifier described in Q. S. T. for February, 1929, pages 20 to 22, and provided with an external grid. Various forms of relay tubes are also illustrated in Electronics for March 1933, pages 70 to 72. The cathode **2** is heated from a low voltage winding **5** of a transformer T, the primary winding of which is connected across the terminals of an alternating current source **6—7**. A suitable load represented by lamp **8** is connected in a circuit across the terminals 6—7 in series with the anode-cathode elements of the tube 1. High voltage winding 9 of transformer T is shunted by a resistance 10, and one terminal of the winding is connected to the cathode heating circuit by switch 9*a*. A variable contact 10*a* on resistance 10 is connected to the grid 4 of the tube by switch 4*a*. The polarity of winding 9 is such that when the anode 3 is positive with respect to the cathode 2, the grid 4 is negative with respect to the cathode.

With the arrangement as described above, it is possible to vary the amount of current flowing in the load 8 by moving the variable contact 10*a*. It will be understood that when the contact is moved to increase the negative voltage impressed upon the grid, the starting of the arc during the pulsation when the anode 3 is positive with respect to cathode 2 is increasingly delayed, thereby resulting in a decrease in the effective current flowing through the load 8. As the voltage on the grid is increased, a point is reached where the control of the grid prevents current from flowing in the anode circuit throughout the positive pulsation, and no current flows in the load. In varying the grid voltage from a low value up to the critical cut-off value, the anode current progressively decreases in value to a definite minimum just at the point of cut-off. I find that by using an alternating current control voltage and an external grid, the cut-off value of the control voltage is much smaller than when using a direct current control voltage. For example, I find that when a variable direct current voltage is applied to an external grid surrounding the tube of a type 866 hot cathode mercury vapor rectifier, the critical voltage necessary to prevent current from flowing in the anode circuit is of the order of 600 volts, where the anode voltage is 120 volts, whereas when a variable alternating current voltage is applied to the grid, as indicated above in connection with Figure 1, the critical cut-off voltage is of the order of 90 to 120 volts, or lower, depending upon the size and arrangement of the grid. No such difference in the values of the cut-off voltages is noted in the case of a relay of the type employing an internal grid located in the space discharge path. The reason for the difference in values of voltages required in the two cases is not entirely clear, but it is possible that the mercury vapor film which condenses on the glass wall inside of the tube plays some part in the action of the tube. It will be noted that this film and the external grid surrounding the tube, with the glass wall between, constitute a condenser element.

I have discovered that it is possible to obtain a wider progressive variation in the anode current by galvanically insulating the grid from the other elements of the tube, that is, by providing a connection to the grid which will transmit alternating current but not direct current. This may be accomplished by inserting a small condenser as at 11 in the connection between the transformer winding 9 and the cathode heating circuit by moving switch 9*a* to the dotted position, or at 12 in the connection between the variable contact 10*a* and the grid 4 by moving switch 4*a* to the dotted position, or in both places if desired. It will be understood that the natural capacity of winding 9 with respect to the coil 5 may in some cases serve the function of condenser 11, and a separate physical condenser will not be required, or switch 9*a* could be left in a neutral position. When a capacity element is provided either at 11 or 12 in Figure 1, variation of the contact 10*a* results in a progressive variation in the current flowing in the anode circuit, and, in this case, it is possible to reduce the anode current substantially to zero without the critical cut-off action described above. In other words, when the grid is galvanically insulated as described, and the control voltage applied to the grid is varied, the variation of the anode circuit is smooth and progressive from full value down to substantially zero, whereas when the control voltage is applied through a galvanic connection, there is first a progressive reduction of the anode current down to a certain minimum value and then, upon further increase in the value of the control voltage, the anode current is suddenly or sharply cut-off. Good dimmer action is obtained in both cases, but the minimum current value for the galvanically insulated grid circuit is lower than for the circuit with the galvanic connection, that is to say, the galvanically insulated grid circuit gives a wider dimming range. I am not prepared to explain the theory of the action of the circuit as described, but the action is very definite and easily demonstrated. It will be understood that the anode current may be varied by allowing the movable contact 10*a* to remain fixed and varying the value of either the capacity elements 11 or 12, or by varying both, in case both are employed.

While I do not wish to be limited by any theory of operation of my invention, the effect of inserting a capacity element in the control circuit to galvanically insulate the grid from the remaining elements of the tube appears to render the control effective in the second half of the positive anode voltage pulsation where the anode voltage is decreasing. I am not prepared to explain just how this result takes place, but it is likely that the provision of the capacity element permits either the grid or the vapor film on the inside of the tube, or both, to assume and hold a charge which renders the control effective in the second quadrant of the anode voltage cycle. I have discovered that when a capacity element is not employed in the control circuit, and the movable contact 10*a* is moved to a point where the arc is completely extinguished, opening the control circuit at any point between the grid and the cathode heating circuit does not immediately restore the arc, but there is a definite time delay before the arc starts.

The arrangement shown in Figure 2 is a simplification of the arrangement shown in Figure 1; similar parts being represented by like reference numerals. In this figure the shunt resistance 10 has been omitted, and control is accomplished by means of a variable condenser 12 connected between the winding 9 and the grid 4. An alternative control may be obtained by the variable condenser 11 by moving switch 9*a* to the dotted position, but it will be understood that both variable condensers may be used if desired. When using one variable condenser at 12, the other end of winding 9 may be connected directly to the cathode circuit by switch 9*a* or may be left free and disconnected where the natural capacity of the winding 9 with respect to the winding 5 is sufficient to provide the needed capacity by placing switch 9*a* in a neutral position. The control action of a variable condenser located at 12 is more effective than by a variable condenser at 11, due to the fact that when the condenser is connected at 11 the fixed capacity between windings 9 and 5 is effectively in shunt to the condenser 11. It will be understood that when the capacity of the variable condenser is increased, the effect is to increase the value of the restraining voltage applied to the grid 4, which results in a decrease in the effective value of the anode current. In both Fig. 1 and Fig. 2, switches 4a and 9a have been shown merely for convenience illustrating various operative conditions of the circuits, and it will be understood that where only one operative condition is required the necessary connections may be made without the use of switches.

Control circuits shown in Figures 1 and 2 may be employed in any alternating current system where it is desired to vary the current or power supplied to a circuit. For example the control circuits may be employed for dimming theater lights; for starting electric motors; for varying the current supplied to an electric sign; for regulating the current or voltage in a transmission line; and for many other purposes which will be obvious to one skilled in the art.

In Figure 3 I have shown an adaptation of the circuit illustrated in Figure 2 for flashing a neon sign. In this case the primary winding of a transformer 13 is connected in the place of the load 8, and the high voltage secondary winding of this transformer is connected to the neon tube of the flashing sign S. The variable condenser 12 is continuously rotated by means of a motor 14, and a variable resistance 15 is inserted in the anode-cathode circuit for the purpose of obtaining proper adjustment of the anode current. It will be understood that as condenser 12 is rotated from minimum to maximum capacity, the brilliancy of the neon lamp is controlled from maximum to minimum, and this variation in brilliancy is rendered periodic by the continuous rotation of the condenser 12. By proper adjustments of the constants of the circuit, and in particular the values of condensers 11 and 12, it is possible to obtain a fluttering condition of operation of the sign, that is, the circuit produces an additional variation of higher frequency than the variation produced by condenser 12, and the two variations occurring simultaneously result in a fluttering effect. In one installation of the arrangement shown in Figure 3 which I have successfully operated from an ordinary house lighting circuit having a voltage of 110 volts, the tube employed was a mercury vapor rectifier having a hot cathode mounted in one end of a glass bulb and an anode mounted in the other end, and the grid constituted a copper wire screen surrounding the tube. The winding 9 of transformer T had a terminal voltage of 550 volts, and variable condenser 12 had a maximum capacity of 10 micro-micro-farads. The fixed condenser 11 had a capacity of the order of 250 micro-micro-farads. The value of the resistance 15 and the ratio and capacity of the transformer 13 depends upon the characteristic of the neon sign connected to the transformer.

In Figure 4 I have shown an adaptation of the circuit shown in Figure 2 as a burglar alarm. In this arrangement the load 8 is replaced by a signal device or a bell 16 and a variable resistance 17. Also, a conductive plate or grid 18 is connected to the grid element 4 of the tube and is arranged in the locality to be protected against burglars. When the condenser 12 is adjusted so that the arc within the tube 1 is just prevented from forming, the approach of a person or any conducting body within the vicinity of the plate 18 will reduce the control potential applied to the grid 4 and permit the arc to be established, thereby energizing the signal 16. The nearer the conducting body approaches the plate 18, the greater will be the current flow in the anode circuit. It is obvious that the circuit of Figure 1 may also be adapted for use as a burglar alarm, and, if the condensers are omitted, the circuit will produce more of a trigger like action than the circuit of Figure 4, due to the operation which results in the abrupt establishment and cutting-off of the minimum anode current for slight variations below and above a critical value of the control voltages.

The arrangements described above may be employed for the purpose of detecting the passage of persons or objects along a passageway by placing the capacity plate 18 at a point along the passageway so that the body or object to be detected passes near the plate. The variation in the anode current caused by the passage of such persons or objects may be utilized through well known means for indicating or recording the number of passages taking place, or for indicating the presence of an object at a certain point in the passageway. The indicating device may be located at a point remote from the control tube. Furthermore, with the arrangement shown in Figure 4, it is possible by an indicating meter 16a to obtain an indication of the nearness or proximity of the object with respect to the plate 18. The arrangement of Figure 4 may be modified by omitting the plate 18 and by forming the variable condenser 12 of plates of suitable size arranged on opposite sides of a passageway as indicated in Fig. 4a. The condenser plates are indicated at 12a and 12b, and the object to be detected is indicated at 19 between the plates. With this modification, the tube is normally inactive, but the passage of an object between the plates of the condenser causes the arc in the tube to strike, and the resulting current operates the signal or recording device 16.

In the circuits of Figs. 1 to 4, the potential applied to the control electrode is derived from the same source that supplies current to the cathode-anode circuit, but the control potential may be supplied from a separate source as shown in Fig. 5. In this arrangement, the cathode of the tube is supplied with heating current from transformer *Ta* connected to the source 6—7, and the control potential is supplied from a separate alternating current source G through transformer *Tb*, resistance 10 and variable condenser 12. This circuit is also subject to the same variations in arrangement as the circuits of Figures 1 and 2 as described above. The sources 6—7 and G may be of the same or different frequency. Where one frequency is a harmonic of the other, the relative phase relation of the two sources should be adjusted so that the control electrode is negative at the beginning of the positive pulsation, of the anode potential. Under these conditions and where the grid source is an even harmonic of the anode source, the anode potential may be reversed in phase without disturbing the control action, since the phase relation between the positive anode pulse and the grid wave will be the same for either direction of connection of the anode source.

The circuit of Figure 5 may be employed as a modulator circuit where the source 6—7 is of a frequency above audibility and the source G comprises a source of signalling currents such as a microphone circuit. The modulated currents flowing in the anode-cathode circuit may be supplied to a separate circuit by substituting a transformer 20 for the load 8. For this purpose a switch 21 is shown in Fig. 5, but it will be understood that in practice only one form of load circuit will be used in any given installation.

In the preferred form of relay tube the grid or control electrode is mounted external of the enclosing envelope, but it will be understood that the control electrode may be mounted inside of the envelope where provision is made to insulate it from the ionized discharge or from the space discharge path of the tube. Such an arrangement is illustrated in Figures 6 and 7, where the grid 4 is in the form of a ring of wire netting located inside the tube envelope and provided with a coating of insulating material. Also, the tube envelope need not be formed entirely of insulating material but may have sections formed of metal.

While I have illustrated various forms of my invention in which only one-half of the alternating current wave is utilized in the anode-cathode circuit, it will be obvious that an additional control tube may be provided to utilize the other half of the wave and to provide a full wave control circuit. It is also obvious that instead of connecting the grid control circuit to a point on the cathode heating circuit, this circuit may be connected to the anode lead or to any point on the anode-cathode circuit. The modified connection is obtained in Figure 4a by the use of switch 22, but it will be understood that the connection may be made directly to the anode without the use of the switch.. Other modifications coming within the scope of my invention will be obvious to those skilled in the art.

What I claim is:

1. An electric control system comprising a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable vapor, and a control electrode insulated from the space current path of said device, an alternating current circuit including the space current path of said device, and means for impressing upon said control electrode an alternating voltage of fixed phase and of variable amplitude to progressively delay the starting of the arc in said device.

2. An electric control system comprising a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable metallic vapor, and a control electrode associated with the space current path of said device but insulated therefrom, an alternating current circuit including the space current path of said device, means for impressing upon said control electrode an alternating voltage of fixed phase to delay the starting of the arc in said device, and means for varying the value of the voltage supplied to said control electrode to progressively delay the starting of the arc.

3. An electric control system comprising a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, an alternating current circuit including the space current path of said device, means for impressing upon said control electrode an alternating voltage of opposite phase with respect to the voltage applied to said anode, and means for varying the value of the voltage supplied to said control electrode to variably delay the starting of the arc in said device.

4. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, circuit connections between said control electrode and said secondary winding for supplying to said control electrode a voltage opposite in phase with respect to the anode voltage, and means for varying the magnitude of the voltage applied to said control electrode.

5. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode external of said envelope, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, circuit connections between said external control electrode and said secondary winding for supplying to said control electrode a voltage opposite in phase with respect to the anode voltage, said circuit connections including a potentiometer for varying the magnitude of the voltage applied to the control electrode.

6. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space discharge path of said device, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, circuit connections between said control electrode and said secondary winding for supplying to said control electrode a voltage opposite in phase with respect to the anode voltage, said circuit connections including a variable condenser for galvanically insulating said control electrode from said work circuit and for varying the magnitude of the voltage applied to said control electrode.

7. An electric control system comprising a vapor electric device having a cathode and an anode enclosed within an insulating envelope, and a control electrode surrounding said envelope, an alternating current circuit including the space current path of said device, means for impressing upon said control electrode an alternating voltage of opposite phase with respect to the voltage applied to said anode, and means for varying the value of the voltage supplied to said control electrode to variably delay the starting of the arc in said device.

8. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an insulating envelope, and a control electrode external of said envelope, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, circuit connections between said external control electrode and said secondary winding for supplying to said control electrode a voltage opposite in phase with respect to the anode voltage, and means for varying the magnitude of the voltage applied to said control electrode.

9. In an electric control system, the combina-

tion of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, a work circuit including said source and the space current path of said device, means for supplying to said control electrode an alternating voltage of fixed phase and of variable magnitude to variably delay the starting of the arc in said device, and means for galvanically insulating said control electrode from said work circuit.

10. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, a work circuit including said source and the space current path of said device, circuit connections for supplying to said external control electrode an alternating voltage of fixed phase and of variable magnitude to variably delay the starting of the arc in said device, and a condenser included in said circuit connections for galvanically insulating said control electrode from said work circuit.

11. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an insulating envelope, and a control electrode external of said envelope, a work circuit including said source and the space current path of said device, means for supplying to said external control electrode an alternating voltage of variable magnitude and of opposite phase with respect to the anode voltage, and means to galvanically insulate said control electrode from said work circuit.

12. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, a connection from said control electrode to the terminal of said secondary winding of opposite phase with respect to said anode and a connection from the other terminal of said secondary winding to a point on said work circuit, one of said connections including a variable condenser for galvanically insulating said control electrode from the work circuit and for varying the magnitude of the voltage applied to said control electrode.

13. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an envelope containing an ionizable atmosphere, and a control electrode insulated from the space current path of said device, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, a connection between said control electrode and the terminal of said secondary winding of opposite phase with respect to said anode, and a variable condenser included in said connection for varying the magnitude of the voltage applied to said control electrode.

14. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an insulating envelope, and a control electrode external of said envelope, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, a connection from said control electrode to the terminal of said secondary winding of opposite phase with respect to said anode and a connection from the other terminal of said secondary winding to a point on said work circuit, one of said connections including a variable condenser for galvanically insulating said control electrode from said work circuit and for varying the magnitude of the voltage applied to said control electrode.

15. In an electric control system, the combination of a source of alternating current, a vapor electric device having a cathode and an anode enclosed within an insulating envelope, and a control electrode external of said envelope, a work circuit including said source and the space current path of said device, a transformer connected to said source and having a secondary winding, a connection between said control electrode and the terminal of said secondary winding of opposite phase with respect to said anode, and a variable condenser included in said connection for varying the magnitude of the voltage applied to said control electrode.

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