Feb. 19, 1935. P. H. CRAIG 1,992,146

REGULATOR SYSTEM

Filed Nov. 1, 1933

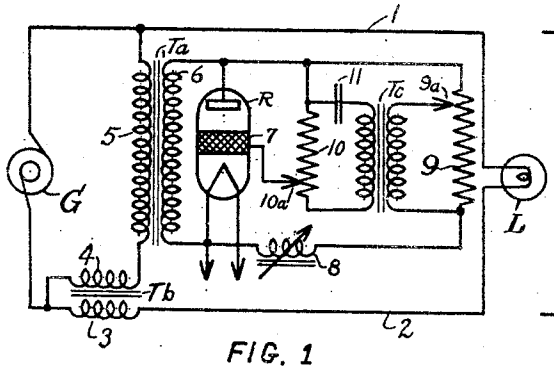

FIG. 1

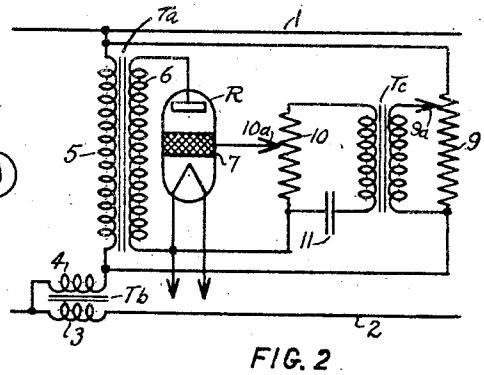

FIG. 2

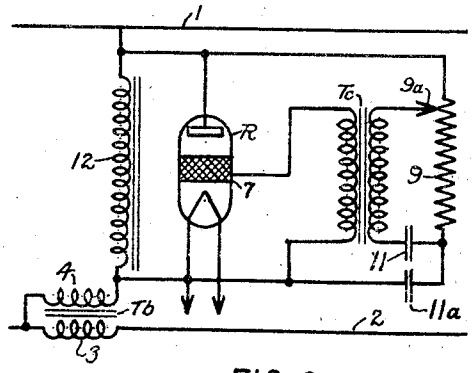

FIG. 3

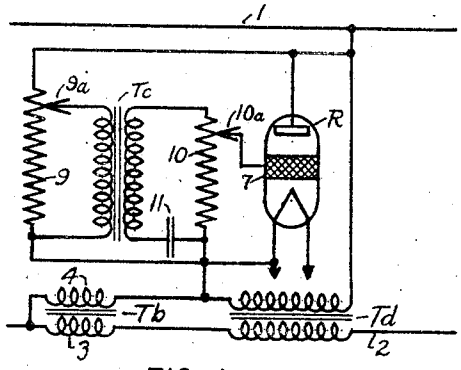

FIG. 4

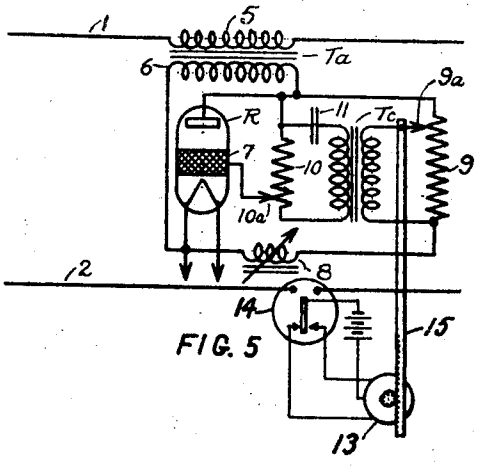

FIG. 5

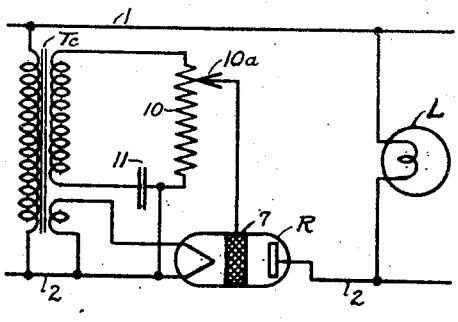

FIG. 6

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REGULATOR SYSTEM

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Application November 1, 1933, Serial No. 696,264

20 Claims. (Cl. 171—119)

This invention relates to systems for regulating the voltage or current in electrical distribution systems.

An object of my invention is to devise a regulating system which will automatically compensate for the voltage drop in a transmission line or circuit as the load changes from one value to another.

Another object is to devise a regulating system to maintain a substantially constant current in a load circuit where the impressed voltage is variable.

A further object of my invention is to devise a regulating system for maintaining a substantially constant current in a load circuit where the load impedance is variable.

Still another object of my invention is to devise a regulating system devoid of vibrating contacts, mechanical relays and the like.

Various modifications of my invention are illustrated in the accompanying drawing in which:

Figure 1 is a circuit diagram illustrating my regulating system applied to a transmission line provided with a booster transformer;

Figures 2 and 3 are circuit diagrams of modified arrangements of the regulator system illustrated in Fig. 1;

Figure 4 is a circuit diagram illustrating my regulator circuit applied to a transmission system provided with a bucking transformer and a boosting transformer;

Figure 5 is a simplified diagram illustrating my regulator circuit effectively connected in series with one conductor of a transmission line;

Figure 6 is a diagram of a regulator circuit taken from my copending application Ser. No. 646,662 filed December 10, 1932.

This application is in part a continuation of my copending application Ser. No. 646,662 filed December 10, 1932.

Referring to Figure 1, conductors 1 and 2 represent an alternating current transmission line or circuit to be regulated. In series with conductor 2 is connected the secondary winding 3 of a booster transformer T*b*, the primary winding 4 of which is connected across the line in series with the primary winding 5 of transformer T*a*. The secondary winding 6 of transformer T*a* is connected to the anode and cathode elements of a vapor electric relay R, such as a hot cathode mercury vapor tube provided with an external control electrode or grid 7. While I prefer to use a relay tube having an external grid, a tube of the type having an internal grid may be used if desired. Connected across the secondary winding 6 is a circuit including a variable inductance 8 connected in series with a resistance 9. The primary winding of a transformer Tc is connected across a variable portion of resistance 9, and the secondary winding of this transformer is provided with a closed circuit including a resistance 10 and a condenser 11 connected in serial circuit relation. One terminal of resistance 10 is connected to a conductor leading to the anode of relay R, and the variable contact 10*a* on the resistance 10 is connected to the control electrode 7. The cathode of relay R is heated from a suitable source of current, not shown.

In describing the operation of Figure 1, it will be understood that a source of alternating current indicated at "G" is connected to conductors 1 and 2 across the terminals at the left end, and a load indicated at L is connected across the conductors at the other end of the line. It is desired to compensate for the drop in voltage along the transmission line with changes in the value of the load currents, and to thereby maintain a constant voltage at the load terminals. It will be understood that relay R is of the arc discharge type which permits the flow of current when the anode is positive with respect to the cathode, and that the starting of the arc during each positive pulsation may be delayed by impressing a negative potential of a predetermined value upon the control grid 7. The duration of the arc during each positive pulsation may be controlled by varying the amplitude of the control voltage, provided the control voltage has a proper phase relation with respect to the voltage impressed across the cathode and anode elements of the tube. As fully disclosed in my copending applications Ser. Nos. 577,691 (filed November 27, 1931) and 646,662 (filed December 10, 1932), the variable control voltage applied to the control grid should lag behind the anode voltage by a phase displacement somewhere between 90 degrees and 180 degrees, or roughly by a displacement of the order of 135 degrees. Accordingly, the values of impedance elements 8, 9, 10 and 11 are adjusted to produce the desired phase displacement of the control voltage with respect to the anode voltage applied to the tube. The value of the voltage applied to the control electrode may be varied either by shifting variable contact 9*a* or variable contact 10*a*, however, it will be understood that only one variable contact is necessary. The voltage impressed upon the grid is adjusted in value so that with a light load carried by the transmission line, a very small current is permited to flow

through the relay R. The high impedance of the transformer Ta under this condition prevents the booster transformer Tb from supplying any appreciable boost to the line. As an increased load is placed upon the line, the current drawn from the line by the primary circuit of the booster transformer increases, and the effective impedance of the tube and its control circuit decreases. The decreased impedance of the tube lowers the effective impedance of the primary winding of transformer Ta, and the current flowing in this circuit is increased beyond the value which would flow if the tube impedance remained constant. The increased current in the primary of the booster transformer increases the boost and off-sets the line voltage drop to maintain the load voltage substantially constant. By shifting the variable contact 9a to include more or less of resistance 9, the compensating action of the regulator circuit may be made to increase or decrease, as desired. It is to be noted that the regulator circuit compensates for voltage drop in the feeder leading from the source to the regulator, as well as for the voltage drop in the line connecting the regulator with the load. By shifting the contact 9a and by properly adjusting the phase determining elements 10 and 11, it is possible to shift the load center for regulation, that is, the point of constant voltage, to any desired point on the line. Where the regulating circuit is applied to a long transmission line it may be located at either end of the line or at any point in the line.

In a circuit for maintaining a constant voltage at the load center of a 2400 volt primary feeder line on a commercial lighting system, I have obtained excellent regulation using a booster transformer Tb having a 2400 volt primary winding and a 240 volt secondary winding; a 2400 volt primary winding and a 600 volt secondary winding for transformer Ta; a mercury vapor relay having a current capacity of 4 amperes; a 700 volt primary winding and a 5000 volt secondary winding for transformer Tc; a resistance 9 of the order of 800 ohms, and resistance 10 of the order of 3.2 megohms, while condenser 11 had a capacity of 0.001 micro-farads. Substantially a constant voltage was maintained at the load end of a line having a resistance of the order of 5 ohms, where the load was varied from zero up to 30 kva. Actual oscillograms taken during operation of the regulator circuit do not disclose any detectable distortion of the wave form of the load voltage which might be due to the asymmetric conductivity of the control tube.

The regulator circuit shown in Figure 2 is a modification of that shown in Figure 1. In this arrangement the control voltage is derived from across the primary winding 5 by connecting resistance 9 across this winding instead of across secondary 6 as in Figure 1. Also, one terminal of resistance 10 is connected to the cathode element of relay R instead of to the anode as in Figure 1. The phase relations necessary in this circuit are the same as discussed above in connection with Figure 1, and the operation of the regulating circuit is substantially the same as that of Figure 1. In Figure 2 as well as in the remaining figures, the source of alternating current G has been omitted for the sake of simplicity, and in Figures 2, 3, 4 and 5, the load L has not been shown.

The regulator circuit disclosed in Figure 3 is a further modification of the circuit shown in Figure 1. In this arrangement the transformer Ta has been replaced by a plain impedance coil 12, and the relay R with its control circuits are connected directly in shunt to this coil. Also, the control circuits in this arrangement differ from the arrangement shown in Figure 1 in that the phase determining condenser 11 has been shifted from the secondary circuit of transformer Tc to the primary circuit, as shown at 11, and the grid 7 of the tube R is connected directly to one terminal of the secondary winding, thereby eliminating resistance element 10. An alternative position for the phase determining condenser is shown at 11a, and, if desired, condensers may be employed both at 11 and 11a. In addition to eliminating one resistance element, the control circuit illustrated in Figure 3 has the advantage that the secondary winding of transformer Tc provides a low resistance path to discharge electrical charges which may accumulate on the grid 7. It will be understood that the control circuits of either Figure 1 or Figure 2 may be employed in Figure 3 instead of the particular circuit shown. The phase relations required in this circuit are the same as in Figure 1, and the operation of the circuit will be apparent from the foregoing description of the operation of Figure 1.

The regulator shown in Figure 4 is a third modification of the circuit shown in Figure 1. In this arrangement a bucking transformer Td is connected in series with the boosting transformer Tb in conductor 2, the primary winding of the two transformers being connected in series across the transmission line, and the relay R together with its control circuits are connected in shunt with the primary winding of the bucking transformer.

With the arrangement shown in Figure 4, the transformers Tb and Td are designed so that at light loads the buck introduced by Td is equal and opposite to the boost introduced by Tb, the control voltage on the tube R being adjusted so that practically no current flows through the tube at light loads. As the load upon the line increases, the effective impedance of the tube R decreases, thereby shunting more current away from and effectively reducing the buck of transformer Td, and also increasing the boost of transformer Tb, thus compensating for the drop in the line voltage due to the increased load.

In Figure 5 I have shown another form of regulating circuit in which the primary winding of transformer Ta is inserted in series with one of the transmission line conductors, and the relay control circuits are the same as shown in Fig. 1. With the circuit properly adjusted, and contact 9a remaining set, the circuit operates to maintain a constant voltage across the load. In case it is desired to use the circuit of Fig. 5 as a constant current regulator, contact 9a may be automatically varied by means of a reversible motor 13 controlled by a contact making meter 14, the motor 13 being operatively connected to shift contact 9a by any suitable mechanism such as a rack and pinion connection 15. It will be understood that elements 13, 14 and 15 are not used when the circuit is used as a constant voltage regulator.

Operation of the circuit shown in Figure 5 will first be described for operation as a constant voltage regulator. The impedance of the series transformer Ta is normally designed to absorb part of the potential applied to the line and to limit the amount of current flowing therein. The control voltage of the tube is adjusted so that

normally a small current flows through the tube, which permits a somewhat larger current to flow in the line circuit than when the tube is inoperative. Assume that the load on the transmission line increases above the normal value, tending to cause more current in the line and a greater line drop. The increased line current results in a greater current flowing through the tube, and a corresponding decrease in the impedance of the tube, whereby the effective impedance at the terminals of the primary winding of transformer T*a* is reduced, and the decrease in voltage drop across this winding offsets the increase in line voltage drop. It will be obvious that the control circuit of Fig. 5 may be connected as in Fig. 2, or a choke coil may be substituted for transformer T*a* as in Fig. 3, and the control circuit of Fig. 3 may be used, if desired.

In case the circuit of Figure 5 is to be employed as a constant current regulator, for example, to maintain a constant current in a series lighting circuit, where the load voltage may vary as much as fifty per cent, the automatic contact shifting apparatus 13, 14 and 15 will be used. The meter 14 in this case will be a contact-making ammeter which will complete a low-current contact at 6.5 amperes and a high-current contact at 6.7 amperes. The lower contact completes a circuit through the motor 13 to drive the contact 9*a* in a direction to decrease the voltage applied to the grid 7 and thereby decrease the impedance reflected into the line, which permits more current to flow through the line circuit. Should the line current increase to 6.7 amperes the motor will run in the opposite direction to increase the voltage applied to the grid of the tube R and thereby increase the impedance reflected into the line circuit and reduce the line current. The operation of the system is such as to maintain a constant current of 6.6 amperes regardless of the number of lamps which are connected in series with the load circuit. It will be understood that the diagram of Figure 5 is purely schematic, and various other arrangements may be employed for shifting the contact 9*a* in response to current variations. It will also be understood that the magnitude of the control voltage applied to the tube R might be varied in other ways as by shifting the contact 10*a*, or in any other suitable manner as by varying the value of one or more of the impedance elements in the control circuits. Also, when the contact shifting elements 13, 14 and 15 are employed, the control voltage need not be derived from across the winding 6, but the terminals of the resistance 9 might be connected across the line conductors 1—2 on either side of transformer T*a*.

In the arrangement shown in Figure 6 the tube R is connected directly in one of the line conductors in series with a load L, and the transformer Tc for supplying the control voltage to the tube is connected across the line conductors 1—2. This simplified circuit has been disclosed in my copending application Ser. No. 577,691 and 646,662.

The circuit of Figure 6 has an inherent regulating action as follows: As the anode becomes positive with respect to the cathode, the grid becomes negative. An increase in the value of the line voltage tends to cause a greater anode current to flow, but this tendency is offset by an increase in the negative potential applied to the grid tending to reduce the anode current. By proper adjustment of the circuit constants, a substantially constant current will flow through the load even though the line voltage varies a substantial amount. This arrangement will also operate like Fig. 5 to compensate for the variable line drop due to varying load currents.

In the arrangement shown in Fig. 1, transformers T*a* and T*b* may be combined into one unit. For example, a three-legged transformer core is provided, the two outside legs carrying the primary winding 4 and the secondary winding 3 respectively of the booster transformer, and the tube winding 6 is carried by the center leg of the core. The circuit for supplying the control voltage may be any of the circuits of Figures 1 to 3 as desired. It will be understood that winding 6 may be placed on one of the outside legs, and the center leg would then carry the other booster transformer winding.

In Figs. 1 to 5 and 7 the cathode heating circuits are not shown, but it will be understood that heating current is supplied to the cathodes through suitable transformers connected to the source of alternating current. It will also be understood that the variable inductance 8 may be dispensed with by proper design of the other elements in the control circuit. It will be noted that in addition to serving as a phase control element, this variable inductance also serves to prevent excessive distortion of the control voltage applied to control electrode 7.

In all the various forms of regulator circuits illustrated and described, only one vapor electric relay has been disclosed, which permits the passage of current through the relay for only a variable portion of one pulsation of the alternating current wave. It will be obvious that in each case an additional control relay may be provided and connected in the opposite direction to provide full-wave operation of the various circuits. It is also obvious that instead of deriving the control voltage from across the terminals of windings 5, 6 and 12 as shown, the control circuits may be connected across only a portion of these windings.

It will be understood that, if desired, the control voltage for the system of Fig. 6 may be derived from in shunt to the anode-cathode elements of the tube R in the manner shown in any of Figs. 1, 3 or 4.

It is to be noted that one advantage of deriving the control voltage from a connection in shunt to the terminals of the tube, or in shunt to an impedance connected across the tube, is that a definite phase relation may be maintained between the cathode-anode potential of the relay and the control voltage applied to the grid, regardless of load or other circuit conditions.

While I prefer to derive the control voltage from in shunt to the tube or in shunt to a part of an impedance element connected across the tube as described, so that the control voltage varies in value in accordance with the cathode-anode voltage of the tube, fairly good regulation may be obtained by using a control voltage of substantially constant value. For this purpose the control voltage may be derived from across the line conductors, preferably on the input side of the regulator, and vary in accordance with changes in line voltage, or it may be derived from any part of the circuit having a substantially constant phase relation with respect to the anode-cathode voltage of the tube. If desired, provision may be made to maintain the control voltage constant and independent of line voltage variations.

In the appended claims, the term "variable

current circuit" applies either to the load circuit proper or to the primary circuit of the booster transformer. The term "translating device" is intended to cover either a load device or a device such as the booster transformer Tb disclosed in Figures 1 to 4. The term "in series with" is to be interpreted broadly to cover either a connection directly in series with another element, as where the tube R is connected in series with the load L in Figure 6, or effectively in series, as where the tube R is connected effectively in series with the load in Fig. 5 by means of the transformer Ta. Also, the term "in shunt to" is to be interpreted broadly to cover either a direct shunt connection of the exciting or control circuit across the relay R as shown in Figures 1, 3, 4 and 5, or an effective shunt connection as shown in Figure 2 through transformer Ta.

Various modifications of my invention will be obvious to those skilled in the art, and all such modifications as fall within the terms of the appended claims are considered as falling within the scope of my invention.

What I claim is:

1. In a regulating system, a source of alternating current, a translating device, an arc discharge device connecting said translating device to said source and having a control electrode, and an exciting circuit for said control electrode connected in shunt to said discharge device to variably delay the starting of the arc in accordance with variations in magnitude of the voltage across said discharge device.

2. In a regulating system, a source of alternating current, a translating device, an arc discharge device connecting said translating device to said source and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage variable in amplitude and of fixed phase displacement lagging the voltage across said discharge device of the order of 135 degrees to variably delay the starting of the arc.

3. In a regulating system, a source of alternating current, a translating device, an arc discharge device connecting said translating device to said source and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage variable in amplitude and of fixed phase displacement lagging the voltage across said discharge device more than 90 degrees and less than 180 degrees to variably delay the starting of the arc.

4. In a regulating system, a source of alternating current, a circuit connected to said source including a translating device, an impedance element connected in said circuit in series with said translating device, an arc discharge device connected in shunt to said impedance element and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage to delay the starting of the arc in accordance with variations in voltage across said discharge device.

5. In a regulating system, a source of alternating current, a circuit connected to said source including a translating device, an impedance element connected in said circuit in series with said translating device, an arc discharge device connected in shunt to said impedance element and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage variable in amplitude and of fixed phase displacement lagging the voltage across said discharge device more than 90 degrees and less than 180 degrees to variably delay the starting of the arc.

6. In a regulating system, a source of alternating current, a circuit connected to said source including a translating device, an impedance element connected in said circuit in series with said translating device, an arc discharge device connected in shunt to said impedance element and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage variable in amplitude and of fixed phase displacement lagging the voltage across said discharge device of the order of 135 degrees to variably delay the starting of the arc.

7. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, an impedance element connected in series with said potential winding, an arc discharge device connected in shunt to said impedance element and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage to delay the starting of the arc in accordance with variations in voltage across said discharge device.

8. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, an impedance element connected in series with said potential winding, an arc discharge device connected in shunt to said impedance element and having a control electrode, and a circuit connected in shunt to said discharge device for supplying to said control electrode an alternating voltage variable in amplitude and of fixed phase displacement lagging the voltage across said discharge device more than 90 degrees and less than 180 degrees to variably delay the starting of the arc.

9. In a regulator system, a source of alternating current, a circuit connected to said source including a translating device, an impedance element connected in said circuit in series with said translating device, an arc discharge device connected in shunt to said impedance element and having a control electrode, the space current of said discharge device being supplied by the potential drop across said impedance element, and means for supplying to said control electrode an alternating voltage of fixed phase and variable amplitude to delay or advance the starting of the arc respectively in accordance with increase or decrease in current flowing in said circuit.

10. In a regulating system, a source of alternating current, a load circuit connected to said source including a translating device, an impedance element connected in said circuit in series with said translating device, an arc discharge device connected in shunt to said impedance element and having a control electrode, a circuit for supplying to said control electrode an alternating voltage to delay the starting of the arc, including means to vary the amplitude of said voltage, and means responsive to current in the load circuit for operating said amplitude varying means to

maintain a substantially constant current in said load circuit.

11. In a regulator system, a source of alternating current, a transmission line of appreciable resistance connected to said source, a transformer having a current winding and a potential winding, said current winding being connected in series with one of the conductors of said transmission line, an arc discharge device connected in circuit with said potential winding and having a cathode, an anode and a control electrode, the space current of said discharge device being supplied by said potential winding, and a circuit for deriving from said source an exciting voltage for said control electrode of substantially fixed lagging phase with respect to the anode-cathode voltage for delaying the starting of the arc.

12. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connection in shunt to said circuit, and an impedance element including an arc discharge device connected in series with said potential winding, said impedance element having a variable impedance characteristic responsive solely to the current flowing in said potential winding and presenting a decreasing impedance with increasing current for maintaining a substantially constant voltage across said load circuit for varying values of load current.

13. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, and an impedance element connected in series with said potential winding, an arc discharge device connected in shunt to said impedance element, said arc discharge device having a variable impedance characteristic responsive solely to the current flowing through said potential winding and presenting a decreasing impedance with increasing current for maintaining a substantially constant voltage across said load circuit for varying values of load current.

14. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said load circuit, and an arc discharge device connected in series with said potential winding having a variable impedance characteristic responsive solely to the current flowing through said potential winding for maintaining a substantially constant voltage across said load circuit for varying values of load current.

15. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, a second transformer having a primary winding connected in series with the potential winding of said booster transformer, an arc discharge device having a cathode, an anode and a control electrode, a secondary winding on said second transformer connected to supply space current to said arc discharge device, and a circuit connected across one of the windings of said second transformer for supplying to the control electrode an alternating voltage having a lagging phase displacement with respect to the anode-cathode voltage.

16. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, a second transformer having a primary winding connected in series with the potential winding of said booster transformer, an arc discharge device having a cathode, an anode and a control electrode, a secondary winding on said second transformer connected to supply space current to said arc discharge device, and a circuit connected across the primary winding of said second transformer for supplying to the control electrode, an alternating voltage having a lagging phase displacement with respect to the anode-cathode voltage.

17. In a regulating system, a source of alternating current, a load circuit connected to said source, a booster transformer having a current winding connected in series with said load circuit and a potential winding connected in shunt to said circuit, a second transformer having a primary winding connected in series with the potential winding of said booster transformer, an arc discharge device having a cathode, an anode and a control electrode, a secondary winding on said second transformer connected to supply space current to said arc discharge device, and a circuit connected across the secondary winding of said second transformer for supplying to the control electrode an alternating voltage having a lagging phase displacement with respect to the anode-cathode voltage.

18. In a regulator system, a source of alternating current, a variable current circuit connected to said source, an arc discharge device connected in series with said circuit, and means for variably delaying the starting of the arc in said device solely and directly in accordance with current variations in said variable current circuit.

19. In a regulator system, a source of alternating current, a variable current circuit connected to said source, an arc discharge device connected in series with said circuit and provided with a cathode, an anode and a control electrode, and means for varying the potential of said control electrode with respect to another electrode of said device in accordance with an alternating current having a fixed lagging phase displacement with respect to the anode-cathode voltage and variable in amplitude in accordance with current variations in said variable current circuit.

20. In a regulator system, a source of alternating current, a variable current circuit connected to said source, an arc discharge device connected in series with said circuit and provided with a cathode, an anode and a control electrode, and means for varying the potential of said control electrode with respect to another electrode of said device in accordance with an alternating current having a fixed lagging phase displacement with respect to the anode-cathode voltage of the order of 135 degrees and variable in amplitude in accordance with current variations in said variable current circuit.

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