Dec. 6, 1955 S. C. ROCKAFELLOW 2,726,356

HIGH VOLTAGE REGULATOR

Filed Sept. 24, 1952 2 Sheets-Sheet 1

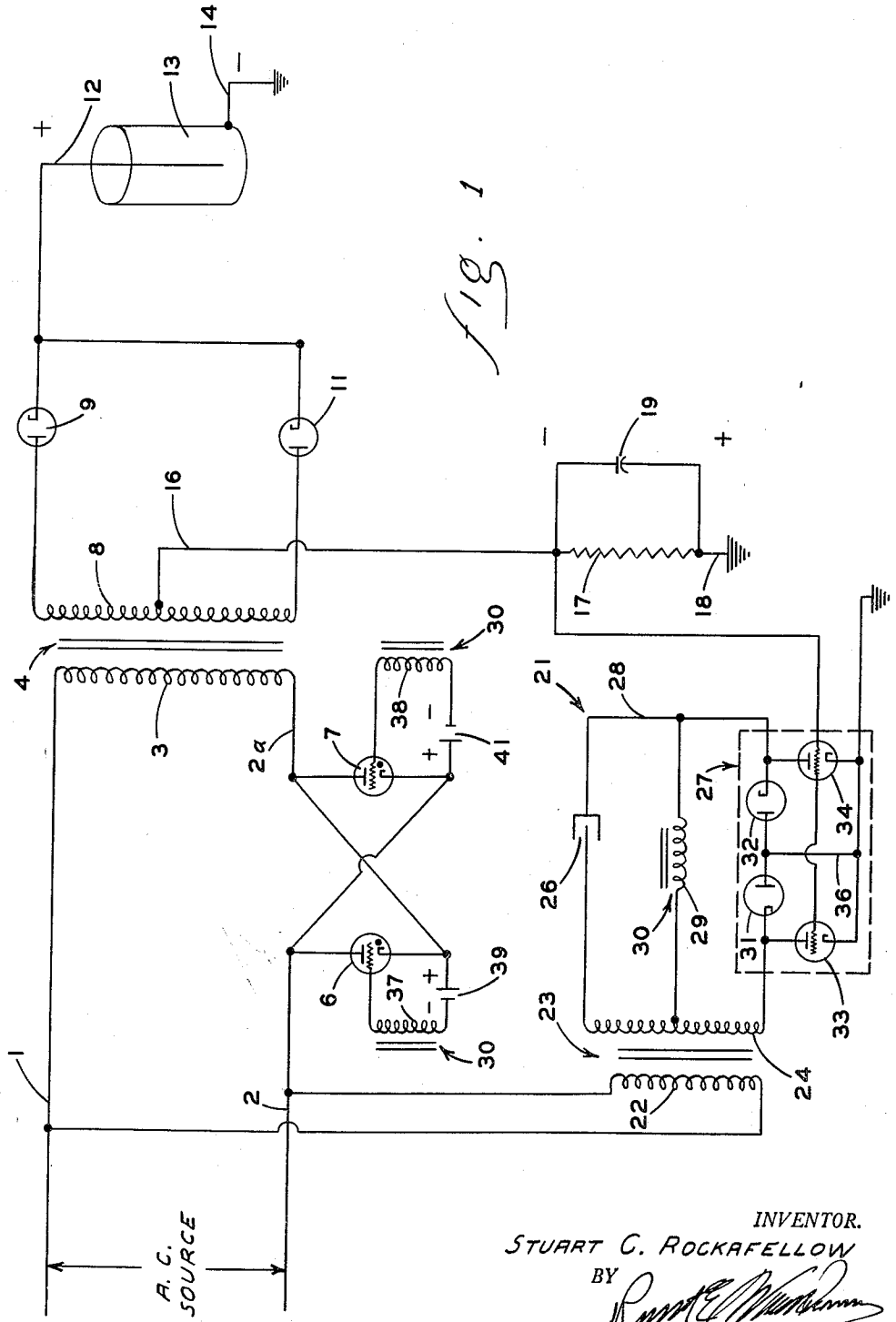


Fig. 1

INVENTOR.
STUART C. ROCKAFELLOW
BY
ATTORNEY

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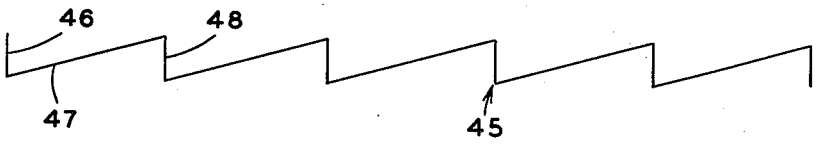


fig. 2

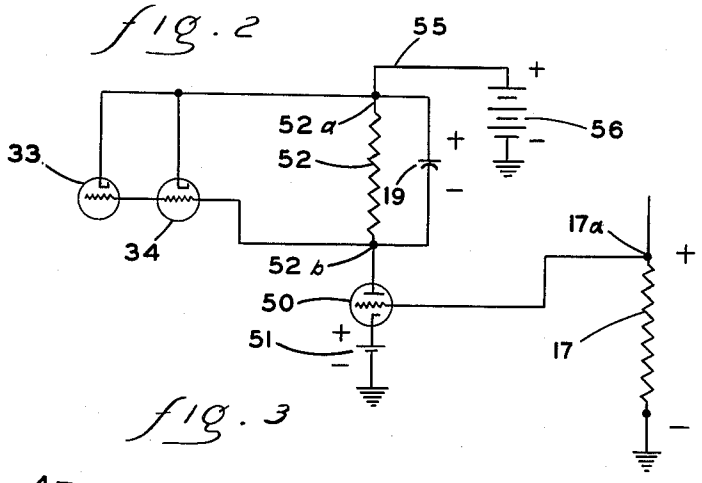


fig. 3

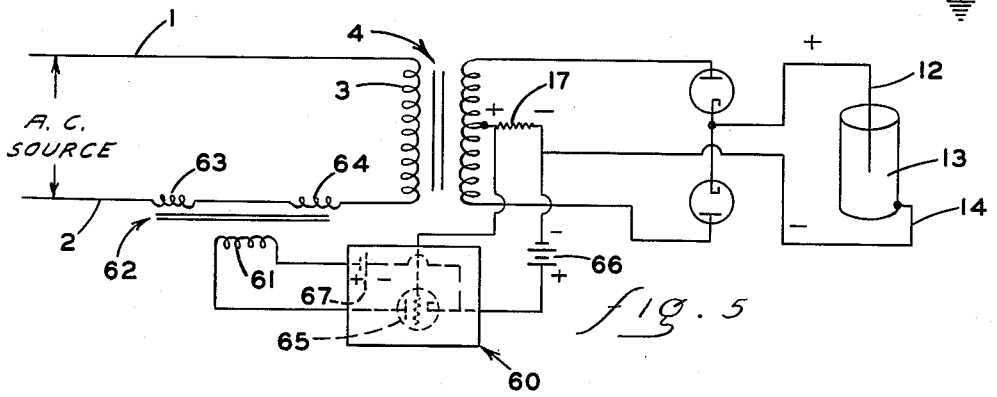


fig. 5

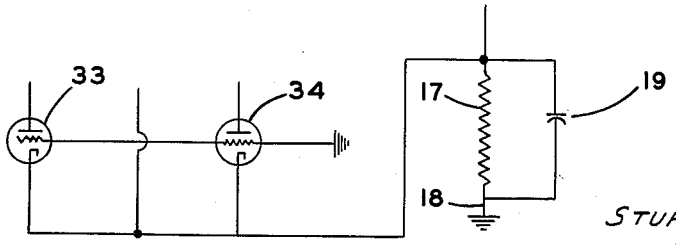


fig. 4

INVENTOR.
STUART C. ROCKAFELLOW
BY
ATTORNEY

United States Patent Office

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HIGH VOLTAGE REGULATOR

Stuart C. Rockafellow, Farmington, Mich., assignor to Robotron Corporation, Detroit, Mich., a corporation of Michigan

Application September 24, 1952, Serial No. 311,220

11 Claims. (Cl. 315—183)

This invention relates to means for regulating high voltage applied to a pair of electrodes which are separated by an ionizable fluid, and it refers particularly to means utilizing the preliminary arcing or "spitting" which occurs if and as the voltage becomes excessive, but previous to complete ionizing of the fluid and the consequent passing of a solid arc, for providing a flow of current through a circuit and utilizing said flow of current for decreasing the voltage applied to said electrodes.

In the provision of means for controlling the application of high voltage to a pair of spaced electrodes, said electrodes being separated by an ionizable fluid, it is often desirable in certain applications to hold said voltage to as high a level as possible without effecting dielectric breakdown of said fluid and arcing between said electrodes. One typical commercial example of this problem occurs in the provision of precipitation apparatus, such as that apparatus utilized for the precipitation of dust, smoke or other foreign particles from the atmosphere. In the operation of such equipment, the efficiency improves with increase in voltage and appears to be at a maximum at the point where arcing is about to occur. Hence, in present practice, it is customary to provide men for watching the equipment and instantly available to reduce the voltage applied to the electrodes by manual control immediately upon the occurence of any preliminary arcing, commonly termed "spitting" in which a series of relatively small arcs pass between the electrodes. This makes possible the passage of some current between said electrodes and it is a purpose of the present invention to utilize the occurrence of such "spitting," and the current passing as a result thereof to regulate the voltage by reducing same sufficiently to avoid full arcing. Further, there is often a substantial corona discharge between the electrodes shortly prior to the passing of a solid arc between them and this further permits the passage of sufficient current between the electrodes to actuate a regulating device for reducing the applied voltage.

Thus, by maintaining the voltage close to the arcing point, but just enough below same to prevent arcing, the efficiency of precipitation apparatus is greatly improved. Further, the means and method here involved are applicable to a variety of other applications where it is desired similarly to control electric potential between a pair of spaced electrodes which are separated by an ionizable dielectric.

Accordingly, a principal object of the invention is to provide a regulating method applicable to high voltage installations for holding such voltage at a point close to, but below, the point of arcing between a pair of spaced electrodes which are separated by an ionizable dielectric.

A further object of the invention is to provide a method for utilizing passage of current between the electrodes immediately prior to breakdown of the dielectric therebetween for reducing the voltage applied to said electrodes and thereby preventing full arcing.

A further object of the invention is to provide a method, as aforesaid, wherein the current passing between said electrodes prior to full arcing therebetween is caused to effect a voltage drop and then utilizing said voltage drop to reduce the voltage applied to said electrodes.

A further object of the invention is to provide a method, as aforesaid, which will be self terminating in that reduction of said applied voltage will terminate said current passage and termination of said current passage will then permit said voltage again to rise.

A further object of the invention is to provide a method, as aforesaid, wherein said rise in voltage is permitted to occur only at a relatively gradual rate.

A further object of the invention is to provide apparatus for carrying out the methods above outlined.

Other objects and purposes of the invention will be apparent to persons acquainted with equipment of this general type upon a reading of the following specification and inspection of the accompanying drawings.

In the drawings:

Figure 1 represents a circuit diagram of one form of apparatus for practicing the method of my invention.

Figure 2 is a graph showing the magnitude of voltage applied to said electrodes.

Figure 3 represents a modification of the invention for application to instances where the applied potential is reversed with respect to that assumed in connection with the circuit of Figure 1.

Figure 4 represents a further modification of the invention.

Figure 5 represents a still further modification of the invention.

General description

In general, the invention contemplates utilizing the small current flowing by reason of either the corona discharge or by reason of the "splitting" which occurs immediately prior to the passing of a solid arc for controlling a valve which in turn will control the voltage applied to the electrodes. In the particular embodiment here chosen for major illustrative purposes, the current so flowing between the principal electrodes is caused to pass through a resistor and the voltage drop occurring across said resistor by reason of the current passing therethrough is applied as a negative potential to block a pair to shift a phase shift circuit and such shifting is then of vacuum tubes. This increased resistance is utilized utilized to delay the firing of a pair of thyratrons passing, or controlling the passing of, the applied voltage.

Detailed description

Inasmuch as the method of the invention will be best understood by reference to a specific apparatus for practicing said invention, attention is now directed to Figure 1 wherein there is shown a diagrammatic presentation of typical apparatus by which said invention may be practiced.

The conductors **1** and **2** are connected to a suitable source of A. C. potential. Said conductor **1** is connected to one side of a primary winding **3** of a line transformer **4** and the conductor **2** is connected through a pair of back-to-back connected thyratrons **6** and **7** by the portion **2***a* thereof to the other end of said primary winding **3**. The secondary winding **8** of said line transformer **4** is connected at each of its ends through the rectifiers **9** and **11** in a conventional full-wave rectification circuit to the positive electrode **12** of the apparatus, as a precipitation device, with which the invention is to be used. The cathode **13** of said apparatus is connected by the conductor **14** to ground.

The conductor **16** is center tapped into the secondary winding **8** of the line transformer **4** and is then connected

to one end of the control resistor 17. The other end of said control resistor is connected by the conductor 18 to ground. A capacitor 19 is connected around the control resistor 17 to form a time-constant circuit.

As indicated at 21 there is provided a conventional phase shift circuit 21. The primary winding 22 of the transformer 23 is energized from the conductors 1 and 2. The secondary winding 24 is connected at one end to a capacitor 26 and at its other end to one side of a resistance circuit 27. The conductor 28 connects the other side of said capacitor 26 to the other side of said resistance circuit 27. The primary winding 29 of a transformer 30 is connected at one end to a center tap on the secondary winding 24 and at its other end to a point on the conductor 28.

The variable resistor 27 may be of any conventional type responsive to a change in potential. Here it consists of a pair of serially and oppositely connected rectifier 31 and 32, a pair of vacuum tubes 33 and 34 and a conductor 36 connecting the positive terminals of the respective rectifiers to the cathodes of the vacuum tubes. The anodes of the vacuum tubes are respectively connected to the negative terminals of respective rectifiers. Thus, a pulse from the secondary winding 24 in one direction will pass the rectifier 31, travel on the conductor 36 to the cathode of the vacuum tube 34 and pass said vacuum tube 34 to a degree controlled by the potential on the grid of said vacuum tube. A pulse in the other direction will pass through the rectifier 32, travel on the conductor 36 to the cathode of the vacuum tube 33 and pass through said vacuum tube to a degree determined by the potential on the grid of said vacuum tube. Thus, the charge on the grids of said vacuum tube will determine the amount of current passing through said vacuum tubes and the entire resistance circuit assembly 27 will function in the same manner as a resistance and the magnitude of such resistance varies according to the negative charge placed on the grids of the respective vacuum tubes. This circuit is further disclosed and described in detail in my application Serial No. 210,922, now abandoned.

The transformer 30 has two secondary windings 37 potential, as the batteries 39 and 41, and are thence and 38. Each of these are respectively connected in a conventional manner in series with sources of constant connected to the grids and cathodes of the thyratrons 6 and 7, respectively. The said potential sources 39 and 41 are of sufficient magnitude as normally to hold said thyratrons blocked. However, when positive pulses from the secondary windings 37 and 38 are in phase with the pulses from the A. C. source which would otherwise fire the respective thyratrons, said positive potentials will cancel the negative from said constant sources 39 and 41 and permit said thyratrons to fire. As the phase delivered by the phase shifting circuit 21 is shifted by change in potential applied to the grids of the vacuum tubes 33 and 34, the thyratrons will fire at progressively later points on the wave forms of the respectively applied potentials and progressively smaller average potentials will be delivered to the primary winding 3 of the transformer 4.

Operation

Now considering the operation of the apparatus in more detail, it will be understood that a conventional alternating current potential applied to the conductors 1 and 2, and assuming no phase shift in the potentials applied to the grids of the thyratrons 6 and 7, will energize the transformer 4 and act through the secondary winding thereof and the rectifiers 9 and 11 in a known manner to apply a fully rectified potential onto the electrode 12 of the device with which this regulating system is to be used, such as precipitation apparatus. The negative electrode 13 is connected through ground to the conductor 18 and thence through the control resistance 17 by the conductor 16 to the center tap of the secondary winding 8. So long as no current passes between the electrodes 12 and 13 there will be no voltage drop across the resistance 17 and no charge on the capacitor 19. Under these conditions there is no negative charge applied to the grids of the vacuum tubes 33 and 34 and the variable resistance circuit 27 functions substantially at zero resistance and no phase shift is effected by the phase shift circuit 21.

As the potential applied at the A. C. source increases to a point at which arcing between the electrodes 12 and 13 becomes imminent, or as dust or water vapor gathers in the atmosphere between said electrodes whereby to permit their arcing at the voltage than being applied thereto, there will be a preliminary amount of corona discharge between said electrodes and also a small amount of "spitting" which will effect the flowing of a small current between said electrodes and through the control resistance 17. The current through said control resistance 17 will effect a voltage drop thereacross and correspondingly charge the capacitor 19. Inasmuch as the conductor 18 and the cathodes of the vacuum tubes 33 and 34 are both connected to ground, the voltage drop across the control resistance 17 will also make the grids of said vacuum tubes negative with respect to their cathodes by an amount dependent upon the amount of current flowing through said resistance. This will effect an increase in the resistance of the resistance circuit 27 and effect a phase shift in the potential applied to the grids of the thyratrons 6 and 7. Such phase shift will cause said thyratrons to fire at points later in the respective wave forms of the potential applied thereto and thus diminish the average potential applied to the primary winding 3. This will diminish the potential applied to the electrode 12 sufficiently to obviate the danger that the spitting might be converted into a solid arc and it will normally also eliminate the spitting itself and corona discharge.

The termination of flow of current between the electrodes 12 and 13, and consequently the termination of flow of current through the control resistor 17, will eliminate the voltage drop across said resistor. However, the capacitor 19 will maintain the negative potential on the grids of the vacuum tubes with respect to their respective cathodes for such period of time as is required for the capacitor to drain through the control resistance 17. As said capacitor drains through the control resistance 17, and the negative potential on the grids of the vacuum tubes thereby decreases with respect to the cathodes thereof, the phase shifting at the output of the phase shift circuit 21 will progressively diminish. This will permit the thyratrons 6 and 7 to fire at progressively earlier points on the wave forms of the potential applied thereto and the potential applied to the electrode 12 will progressively increase. When it again increases to a point at which corona discharge and "spitting" again occur, current will again pass between said electrodes and through the resistance 17 and the cycle will be repeated. Figure 2 shows by line 45 the variations in the potential applied between the electrodes 12 and 13. The line 46 thereof indicates the drop in potential which occurs when the phase shifting function above described is brought about, line 47 indicates the rise in potential as the capacitor 19 drains through the control resistance 17 and the line 48 indicates the next drop in potential. The horizontal distance between lines 46 and 48 indicates the period between peak potentials which period is determined by the R. C. constant of the circuit involving the control resistance 17 and the capacitor 19.

Modifications

Under some circumstances it will be desirable to operate the equipment with the polarity reversed from that assumed in the foregoing discussion and as shown in Figure 1. In this case, the same circuit as that shown in Figure 1 will function satisfactorily excepting for the

connections between the resistance 17 and the vacuum tubes 33 and 34, together with the placement of the capacitor 19 and this altered portion is shown in Figure 3. Referring now to Figure 3, the resistance 17 is connected from its end 17*a*, which is now the positive end thereof when current flows therethrough, to the grid of an intermediate vacuum tube 50. The cathode of said vacuum tube is connected to the positive side of a small bias battery 51 and thence to ground, and the anode of said vacuum tube is connected through a resistor 52 and a source 56 of anode potential to ground. The capacitor 19 is here connected between the ends of resistor 52. The cathodes of the vacuum tubes 33 and 34 are connected to the end 52*a* of the resistor 52, the same being the end remote from the vacuum tube 50, and the grids of the vacuum tubes 33 and 34 are connected to the end of 52*b* of the resistor 52, the same being the end adjacent the vacuum tube 50.

Thus, when current flows through the resistance 17, to cause a voltage drop therein, the positive potential at the end of 17*a* of the resistor 17 will permit current flow to take place through the vacuum tube 50 and thereby through the resistor 52. A voltage drop through the resistor 52 will thus be transmitted to control the vacuum tubes 33 and 34 in the same manner as the voltage drop in control resistor 17 in Figure 1 is caused to control the vacuum tubes 33 and 34 as shown in the circuit therein.

A further alternative circuit for the case of reversed polarity on the electrodes as compared to the structure of Figure 1, is indicated in Figure 4. The entire circuit is exactly the same as Figure 1 excepting only that the connections from the cathodes and the grids of the vacuum tubes 33 and 34 are reversed with respect to the respective ends of the control resistance 17 as compared to the connection as shown by the corresponding parts in Figure 1. The functioning of this circuit is the same as that described in Figure 1.

A still further modification appears in Figure 5 wherein a saturable reactor is used to control the current flowing through the primary winding 3 of the transformer 4 in place of the phase shift circuit and the thyratron utilized in Figure 1.

In this circuit, the control resistance 17 is connected at each of its respective ends through a source 66 of biasing potential to an amplifier 60, and the output of said amplifier is connected to the direct current winding 61 of a saturable reactor 62. Since the structure of a suitable amplifier is well known in the art, its functioning is schematically indicated by only a single vacuum tube 65 together with a source 67 of anode potential. The alternating current windings 63 and 64 of said saturable reactor are in series with the primary winding 3 of the line transformer 4.

When spitting between the electrodes 12 and 13 occurs here, and a current thereby flows through the resistance 17, the voltage drop across said resistor 17 increases the resistance of the vacuum tube 65 and thus causes less direct current to flow through the winding 61. This, due to the well known characteristics of a saturable reactor, causes a higher reactance in the windings 63 and 64 and thereby decreases the voltage effective on the transformer 4. This, in the manner described above with respect to the circuit shown in Figure 1, decreases the voltage acting on the electrodes 12 and 13 and thereby prevents the undesired arcing.

This circuit, while fully effective and satisfactory for some uses, does not operate quite as quickly as does the circuit shown in Figure 1, inasmuch as the saturable reactor ordinarily takes two or three cycles to effect the desired voltage reduction, and hence its use is somewhat limited.

While I have shown certain specific embodiments of the invention for illustrative purposes, it will be appreciated that many modifications are possible and will be

apparent to persons skilled in the art and the hereinafter appended claims will include such modifications excepting as they are by their own terms expressly limited otherwise.

I claim:

1. In an apparatus for regulating the application from an alternating source of high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a transformer; a pair of thyratrons connected in back-to-back relationship; means conecting one end of the primary winding of said transformer to one terminal of said source and connecting the other end of the primary winding of said transformer through said thyratrons to the other terminal of said source; means including a rectifier connecting the secondary winding of said transformer through said rectifier to said electrodes; a control resistance interposed in said electrode circuit; a source of constant potential in the grid circuit of each of said thyratrons for holding same normally non-conductive; a control transformer having a pair of secondary windings, and each of said windings interposed in said grid circuits respectively in series with said sources of constant potential; a phase shift circuit including a variable resistance, the output of which circuit is connected to energize the primary winding of said control transformer; a circuit responsive to voltage drop across said control resistance to change the value of said variable resistance.

2. The device defined in claim 1 including also a capacitor bridging said resistance.

3. An apparatus for regulating the application from an alternating source of high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arm, the combination comprising: a transformer; a pair of thyratrons connected in back-to-back relationship; means connecting one end of the primary winding of said transformer to one terminal of said source and connecting the other end of the primary winding of said transformer through said thyratrons to the other terminal of said source; means including a rectifier connecting the secondary winding of said transformer through said rectifier to said electrodes; a control resistance interposed in said electrode circuit; a source of constant potential in the grid circuit of each of said thyratrons for holding same normally nonconductive; a control transformer having a pair of secondary windings, and each of said windings interposed in said grid circuits respectively in series with said sources of constant potential; a phase shift circuit including a variable resistance, the output of which circuit is connected to energize the primary winding of said control transformer; said variable resistance including vacuum tubes, and means connecting the negative end of said control resistance to the grids of both of said vacuum tubes and other means connecting the positive end of said control resistance to the cathodes of said vacuum tubes.

4. In an apparatus for regulating the application from an alternating source of high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a transformer; a pair of thyratrons connected in back-to-back relationship; means connecting one end of the primary winding of said transformer to one terminal of said source and connecting the other end of the primary winding of said transformer through said thyratrons to the other terminal of said source; means including a rectifier connecting the secondary winding of said transformer through said rectifier to said electrodes; a control resistance interposed in said electrode circuit; a source of constant potential in the

grid circuit of each of said thyratrons for holding same normally non-conductive; a control transformer having a pair of secondary windings, and each of said windings interposed in said grid circuits respectively in series with said sources of constant potential; a phase shift circuit the output of which is connected to energize the primary winding of said control transformer; a circuit responsive to voltage drop across said control resistance to shift the phase output of said phase shift circuit.

5. In an apparatus for regulating the application from an alternating source of high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising; a transformer; a pair of thyratrons connected in back-to-back relationship; means connecting one end of the primary winding of said transformer to one terminal of said source and connecting the other end of the primary winding of said transformer through said thyratrons to the other terminal of said source; means including a rectifier connecting the secondary winding of said transformer through said rectifier to said electrodes; a control resistance interposed in said electrode circuit; a source of constant potential in the grid circuit of each of said thyratrons for holding same normally non-conductive; a control circuit including potential supplying devices for supplying a variable potential interposed in said grid circuits respectively in series with said sources of constant potential, the polarity of the potential supplied by said control devices being opposed to the polarity of said constant potential; a phase shift circuit the output of which is connected to energize the potential supplying devices and a circuit responsive to voltage drop across said resistance to shift the phase output of said phase shift circuit with respect to said alternating source of high constant potential.

6. In an apparatus for regulating the application from an alternating source of high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a transformer; a pair of thyratrons connected in back-to-back relationship; means connecting one end of the primary winding of said transformer to one terminal of said source and connecting the other end of the primary winding of said transformer through said thyratrons to the other terminal of said source; means including a rectifier connecting the secondary winding of said transformer through said rectifier to said electrodes; a control resistance interposed in said electrode circuit; means applying potential to the grid circuits of each of said thyratrons for holding same normally non-conductive and for varying said potential to render said thyratrons conductive; a phase shift circuit the output of wihich circuit is connected to energize said grid circuits for rendering said thyratrons conductive; a circuit responsive to voltage drop across said control resistance to shift the phase output of said phase shift circuit with respect to said source.

7. In an apparatus for regulating the supplying from an alternating source of a high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a pair of grid controlled space discharge devices connected in back-to-back relationship; a rectifier; means connecting one side of said source through said pair of space discharge devices and said rectifier to one of said electrodes; and means connecting the other side of said source to the other of said electrodes; a control resistance interposed in said electrode circuit; means applying potential to the grid circuits of each of said space discharge devices for holding same normally non-conductive and for varying said potential to render space discharge device conductive; a phase shift circuit the output of which circuit is connected to energize said grid circuits for rendering said space discharge device conductive; a circuit responsive to voltage drop across said control resistance to shift the phase output of said phase shift circuit with respect to said source.

8. In an apparatus for regulating the supplying from an alternating source of a high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a pair of grid controlled space discharge devices connected in back-to-back relationship; a rectifier; means connecting one side of said source through said pair of space discharge devices and said rectifier to one of said electrodes; and means connecting the other side of said source to the other of said control electrodes; a control resistance interposed in said electrode circuit, a source of high constant voltage of constant potential in the grid circuit of each of said space discharge devices for holding same normally non-conductive; means for varying said potential to render said space discharge devices conductive; a phase shift circuit the output of which circuit is connected to energize said last-named means for rendering said space discharge devices conductive; a circuit responsive to voltage drop across said resistance to shift the phase output of said phase shift circuit with respect to said source.

9. In an apparatus for regulating the supplying from an alternating source of a high constant voltage to a pair of primary electrodes and for maintaining said high voltage on said primary electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a pair of control electrode controlled space discharge valves connected in back-to-back relationship; a rectifier; means connecting one side of said source through said pair of space discharge valves and said rectifier to one of said primary electrodes; and means connecting the other side of said source to the other of said primary electrodes; a control resistance composed in said primary electrode circuit; a source of constant potential in the control electrode circuit of each of said space discharge valves for holding same non-conductive; means for varying the potential on the control electrode with respect to the cathode of each of said space discharge valves to render such space discharge valves conductive; a phase shift circuit whose output is connected to energize said last-named means for rendering such space discharge valves conductive; a circuit responsive to voltage drop across said control resistance to shift the phase output of said phase shift circuit with respect to said source of high constant voltage.

10. In an apparatus for regulating the supplying from an alternating source of a high constant voltage to a pair of primary electrodes and for maintaining said high voltage on said primary electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a pair of control electrode controlled space discharge valves connected in back-to-back relationship; a rectifier; means connecting one side of said source through said pair of space discharge valves and said rectifier to one of said primary electrodes; and means connecting the other side of said source to the other of said primary electrodes; a control resistance composed in said primary electrode circuit; a source of constant potential in the control electrode circuit of each of said space discharge valves for holding same non-conductive; means for varying the potential on the control electrode with respect to the cathode of each of said space discharge valves to render such space discharge valves conductive; a circuit responsive to the potential across said control resistance and connected to said last-named means for moving the condition of said space discharge valves toward and away

from a condition of conductivity in response to changes in the voltage drop across said control resistance.

11. In an apparatus for regulating the supplying from an alternating source of a high constant voltage to a pair of electrodes and for maintaining said voltage on said electrodes as close as possible to the arcing point therebetween without actually causing the passing of a solid arc, the combination comprising: a control electrode controlled electric valve; rectifier means connecting one side of said source through said valve and through said rectifier to one of said electrodes; means connecting other side of said source to the other of said electrodes; a control resistance interposed in said primary electrode circuit; a

source of constant potential and means applying same to said valve for normally holding same in one condition of conductivity or non-conductivity; a phase shift circuit whose output is connected to oppose said source of constant potential for controllably altering the potential applied to said valve; a circuit responsive to voltage drop across said control resistance to shift the phase output of said phase shift circuit with respect to the phase of said source of high constant voltage.

References Cited in the file of this patent

UNITED STATES PATENTS

2,569,605 Hall ---------- Oct. 2, 1951