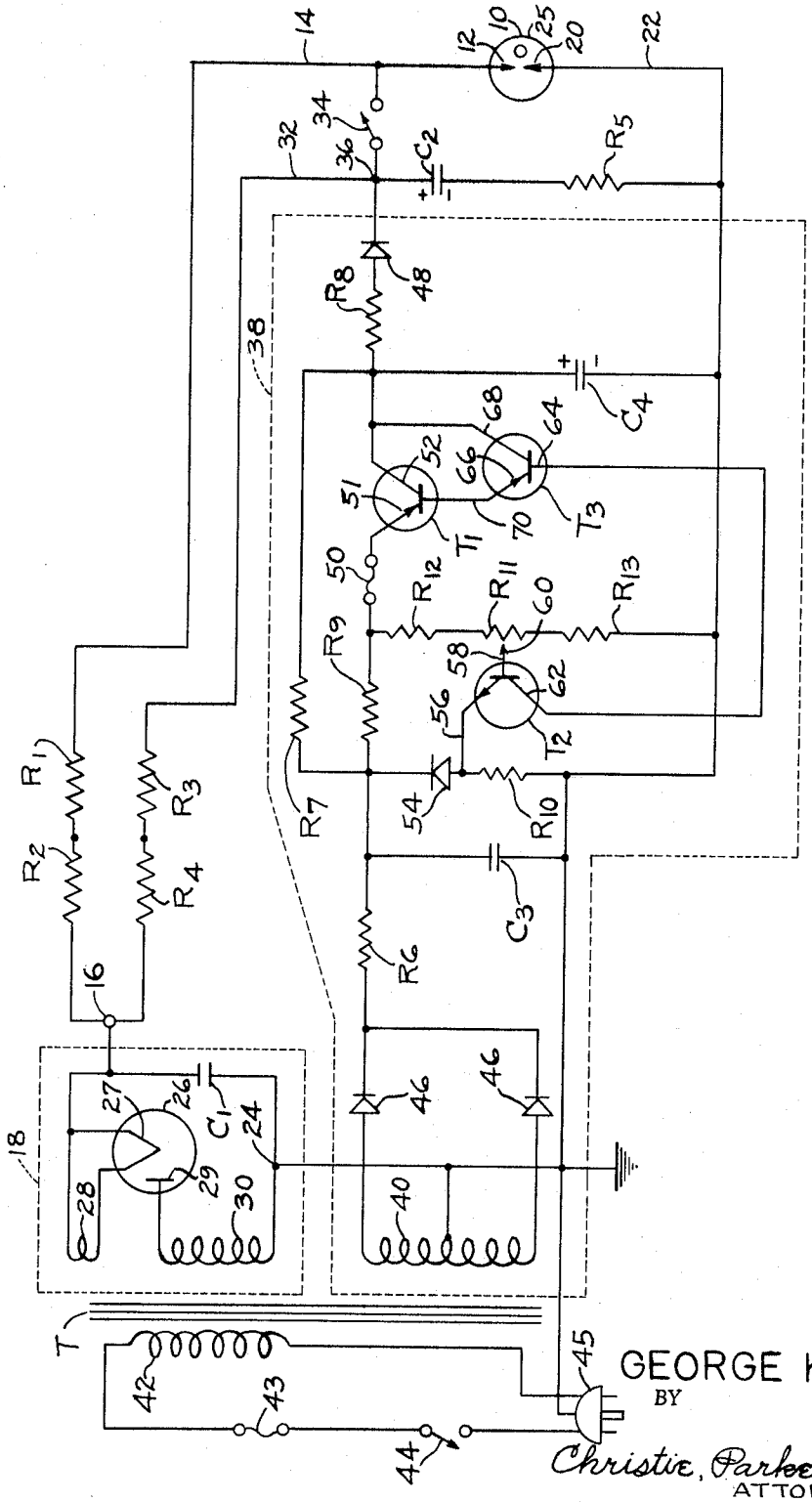
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ELECTRIC ARC CONTROL CIRCUIT

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ELECTRIC ARC CONTROL CIRCUIT

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This invention relates to electrical circuits, and more particularly to an improved starting circuit for a gas-filled lamp, and an improved regulator circuit for use in conjunction with the starting circuit.

Many scientific, industrial, and military applications require lamps which deliver a high-intensity and substantially constant amount of light. Such lamps usually include a pair of electrodes across which an electric arc is maintained as a high-intensity light source. The two electrodes are usually tungsten, and are surrounded by a suitable gas or easily vaporized metal in an envelope. Other examples are carbon arc lamps, which operate in open air, or fluorescent lamps.

The starting of such lamps often presents a problem. A high voltage must be applied to the lamps with sufficient energy to cause ionization of the gas surrounding the electrodes, and heating of the electrodes to such a point that one of them emits enough electrons to support ionization of the surrounding gas at a much lower voltage than the starting voltage.

Previous starting circuits have used a large inductor in series with the lamp, or a Tesla coil, to generate bursts of high energy to strike an arc across the electrodes. These previously used circuits have several disadvantages. For example, the discharge of the inductor is oscillatory, causing the lamp to go on and off several times during the starting cycle. This causes deterioration of the electrodes, and since the electrodes cool between "on" cycles, it is wasteful of stored energy. Moreover the inductor circuits are bulky because, typically, the inductor alone weighs about ten pounds.

Another disadvantage results from the nature of operation of the inductor circuit, which requires that the lamp be short-circuited, forcing a relatively high current to flow through the inductor. The short circuit is removed, and the high voltage is developed across the lamp because of the energy stored in the inductor. Removal of the short circuit requires the use of an expensive vacuum relay, because of the high voltages and currents involved. The operation of the inductor circuit also causes considerable radio interference, and the wiring leads must be short to reduce capacity, and must be heavily insulated to withstand the extreme voltages, particularly if the lamp is not in its socket.

The Tesla coil has the disadvantage of being complex, generating extreme radio interference, and requiring wiring which must be very short because of the high frequencies involved. Finally, the spark gap often proves unreliable in Tesla coil circuits.

This invention provides an inexpensive, simple, and reliable starting circuit for arc lamps. It eliminates heavy inductors and expensive relays. The circuit of this invention also avoids high frequencies, and therefore long leads can be used when required, and there is no radio interference.

Briefly, the starting circuit of this invention includes a first relatively high voltage source with a pair of terminals adapted to be connected across the electrodes of a lamp. The circuit also includes a second electric power source of lower voltage and having a pair of terminals. A rectifier is connected in series with one of the terminals and one of the electrodes of the lamp. The other terminal of the power source is connected to the other electrode.

A capacitor is connected across the electrodes of the lamp. The high-voltage source across the lamp electrodes causes some ionization of the surrounding gas, but ordinarily there is not enough energy in the ionization produced by the high voltage source to heat the electrodes in the lamp to the point that they emit electrons. However, the capacitor is charged to a voltage considerably higher than the voltage existing across the lamp after the initial ionization produced by the high voltage. The voltage across the capacitor builds up until it exceeds the breakdown voltage of the lamp. At this point the lamp voltage drops sharply, allowing discharge of energy from the capacitor into the lamp. This energy is sufficient to cause the ionization in the lamp to become true arc, and decreases the operating voltage of the lamp below that supplied by the low-voltage power source so that the lamp is thereafter kept on by the power from the low-voltage source.

Preferably, the connection of the capacitor across the electrodes is controlled by a switch because this reduces the voltage rating required for the rectifier.

In the presently preferred embodiment of the starting circuit a relatively large filter capacitor is connected across the high-voltage source so that the lamp remains operating even after a momentary power failure or a drop in voltage, say due to the starting of motors connected to the main power line.

Once the lamp is started, it is desirable to have a stable low-voltage power supply connected to it to maintain a steady output.

The low-voltage power source of this invention preferably includes a source of variable voltage having a pair of terminals. A first circuit branch is connected at one end to one of the terminals and adapted to be connected at its other end to a load contact, say a lamp electrode. Means are provided for connecting the other terminal to another load contact, say the other electrode of the lamp. A second circuit branch of variable impedance is connected in parallel with the first branch. Means are provided for sensing variations in the voltage of the source, and means are also provided for automatically changing the impedance of the second branch in response to the sensing means to keep the power delivered to the load substantially constant.

In the preferred regulator circuit, the sensing means is an electron discharge device, such as a transistor, which has a pair of input terminals connected to sense the voltage of the variable source. The device also has an output which develops a signal in accordance with the source voltage. Preferably, the current through the second circuit branch is controlled by another electron discharge device, such as one or more transistors connected in a cascade arrangement to receive the signal from the first electron device and control the current through the second circuit branch accordingly.

These and other aspects of the invention will be more fully understood from the following detailed description and the accompanying drawing, which is a schematic circuit diagram of the presently preferred embodiment of the invention.

Referring to the drawing, a lamp **10** has a first contact or electrode **12** connected through a lead **14** and series-connected resistors R_1 and R_2 to the positive terminal **16** of a high-voltage D.C. source **18**. A second contact or electrode **20** of the lamp is connected through a grounded lead **22** to the negative terminal **24** of the high-voltage source. The lamp may be of any suitable type, but for the purposes of explaining the invention, it is assumed that it is a high-pressure mercury arc lamp, i.e., having a pair of tungsten electrodes enclosed by a quartz envelope **25** which also includes liquid mercury that becomes vaporized to a relatively high pressure when the

electrodes are heated by the application of electrical power.

The high-voltage source includes the usual half wave vacuum rectifier tube **26** having a cathode **27** heated by the application of power from a secondary transformer winding **28** of a transformer T. The tube also includes a plate **29** connected to one end of a secondary winding **30**, the other end of which is connected to the negative terminal **24** and one side of a filter capacitor C_1, the other side of which is connected to the positive terminal **16**.

The positive side of a starting capacitor C_2 is connected through a lead **32** and serially connected resistors R_3 and R_4 to the positive terminal **16** of the high voltage supply. The other side of the starting capacitor C_2 is connected through a current limiting resistor R_5 to grounded lead **22**. A switch **34** is provided to connect the first electrode **12** on the lamp to the positive side of the capacitor C_2 and the positive terminal **36** of a regulated low-voltage D.C. source **38**. The regulated D.C. source includes a secondary winding **40** on the transformer T, which receives its power through a primary winding **42** connected through a fuse **43** and a power switch **44** to a plug **45** adapted to be connected to a conventional source of A.C. line voltage (not shown).

The secondary winding **40** is center-tapped to ground, and its ends are connected to the anodes of respective rectifiers **46**, the cathodes of which are connected in series with resistors R_6, R_7, R_8, and a blocking rectifier **48** to the positive terminal **36** of the low-voltage source. Preferably, the blocking rectifier is of the silicon type with a high Zener breakdown voltage and a high current-carrying capacity in the forward direction.

The resistor R_7 forms a first circuit branch for current delivered by the low-voltage source to the lamp electrodes. One end of a resistor R_9 is connected between resistors R_6 and R_7. The other end of resistor R_9 is connected in series with a fuse **50**, the emitter **51**, and collector **52** of a first transistor T_1 and the point between resistors R_7 and R_8 to form a second circuit branch connected in parallel with the resistor R_7.

A smoothing capacitor C_3 is connected across grounded lead **22** and the point between resistors R_6 and R_7 to smooth the voltage delivered by the rectifiers **46**.

A rectifier **54**, such as a Zener voltage regulator, has its cathode connected between resistors R_6 and R_7. The anode of the rectifier **54** is connected in series with a resistor R_{10} to grounded lead **22**. The emitter **56** of a second transistor T_2 is connected between the resistor R_{10} and the anode of the rectifier **54**. The base **58** of transistor T_2 is connected to a movable tap **60** which is adapted to slide along a linear potentiometer resistance R_{11}, which is connected at its oposite ends to respective ends of resistors R_{12} and R_{13}. The opposite end of R_{13} is connected to grounded lead **22**, and the opposite end of resistor R_{12} is connected between resistor R_9 and the emitter **51** of the first transistor. Ordinarily, the resistors R_{12} and R_{13} are equal, and the tap **60** is set in the center of resistor R_{11}. The collector **62** of the second transistor T_2 is connected to the base **64** of a third transistor T_3, which has its emitter **66** and collector **68** connected in a cascade arrangement with the base **70** and the emitter **52**, respectively of the first transistor T_1. A capacitor C_4 is connected across grounded lead **22** and a point between resistor R_8 and resistor R_7.

A low-voltage regulated D.C. power source was built in accordance with this invention from components of the type having the values indicated by the following table:

Component	*Description*
C_1	0.1 micro f.—200 v.
C_2	0.22 micro f.—600 v.
C_3	7700 micro f.—75 wv. D.C.
C_4	1000 micro f.—75 wv. D.C.
Rectifiers **46**	2—Transistron TR152.
Rectifier **48**	Transistron TR401.

Component	*Description*
Rectifier **54**	Transistron IN3029A.
Transistor T_1	RCA 2N442.
Transistor T_2	RCA 2N647.
Transistor T_3	RCA 2N1183A.
R_1, R_2, R_3, and R_4	4—150K 2 w. 10%.
R_5	22 Ohm 2 w. 10%.
R_6	0.6 Ohm 40 w.
R_7	5 Ohm 200 w.
R_8	0.4 Ohm 25 w.
R_9	5 Ohm 25 w.
R_{10}	1200 Ohm 1 w. 10%.
R_{11}	500 Ohm Linear Pot.
R_{12}	1500 Ohm ½ w. 10%.
R_{13}	1500 Ohm ½ w. 10%.
T	Transformer #150–901.
Tube **26**	2X2A Tube.

A regulated power supply constructed as described with the foregoing components has the Thevenin equivalent characteristics of a steady source of D.C. voltage connected in series with a resistance to the lamp electrodes.

In the operation of the low voltage source, as the line voltage increases, the applied voltage to the emitter of transistor T_2, goes up by the amount appearing between resistors R_6 and R_9, because the voltage drop across the Zener diode **54** is constant. The voltage on the base of the transistor also increases, but not as much, due to the voltage drop in resistors R_{12} and R_{11}. This causes an amplified current to pass through the collector **62** of transistor T_2, and drive transistor T_1 through transistor T_3 to be less conducting so that the impedance of the second branch is increased, thereby reducing the amount of current delivered to the lamp electrodes by the low-voltage power supply. However, since the voltage is higher, the amount of power passing through the lamp remains substantially constant, and therefore the lamp output does not vary significantly.

If the line voltage tends to drop, the signal developed by the collector of transistor T_2 drives transistor T_1 to be more conducting so that the impedance of the second branch is reduced and thereby permits an increased amount of current to flow at the reduced voltage, thereby maintaining a substantially constant power input to the lamp electrodes.

A circuit built with the components given in the foregoing table stabilized a 100-watt mercury lamp against line voltage variation between 105 to 130 volts, with a maximum regulator power dissipation of only 13 watts over normal variations in lamp operating characteristics, and of only 18.5 watts under starting conditions. Normal prior art circuitry would require at least 55 watts power dissipation, and more likely 75 watts power dissipation, in the regulator element under normal variations in lamp operating characteristics. Thus, the circuit of this invention provides stabilized low voltage with a power dissipation of less than ¼ that required by previously available circuits.

Moreover, when $R_9(R_{13}+\frac{1}{2}R_{11})=R_7(R_{12}+\frac{1}{2}R_{11})$,

$$E_o=E_{ref}\frac{(R_{11}+R_{12}+R_{13})}{R_{12}+\frac{1}{2}R_{11}}-i_oR_7$$

where

E_o=the voltage output across lead **22** and the junction of R_7 and R_8

E_{ref}=voltage drop across Zener diode rectifier **54**

i_o=current flowing through resistor R_8.

This is the same as a Thevenin equivalent circuit of a battery (E) in series with a resistance (R). Moreover, the output voltage is independent of voltage variations within the design limits of the system.

In starting the lamp, the plug **45** is connected to a suitable source of line voltage, and switch **44** is closed. This causes a high positive potential, say 1000 volts, to

be applied to the electrode **12** of the lamp. Switch **34** is open. The high voltage applied to the lamp through the current limiting resistors R_1 and R_2 causes gas or metal vapor in the lamp to ionize. There is not sufficient energy in this conduction, however, to heat the electrodes in the lamp to the point that electrons are emitted. The voltage across the lamp therefore remains fairly high, say 60 or 70 volts when new, and possibly 200 volts when old.

Coincident with the ionization of gas or vapor in the lamp, the capacitor C_2 is charged through resistors R_3 and R_4 to the voltage equal to the Zener breakdown voltage of rectifier **48**, say 400 volts, and the low voltage of the power source, which is about 50 volts. This total of some 450 volts is substantially higher than the voltage now existing across the lamp electrodes. The blocking rectifier **48** therefore permits capacitor C_2 to be charged to a much higher voltage than that of the low power source.

Switch **34** is closed to connect the capacitor C_2 and the low voltage source across the lamp electrodes. Capacitor C_2 is discharged into the lamp to produce sufficient heating of the lamp electrodes so that electrons are emitted and the previous ionization becomes a true arc, reducing the operating voltage of the lamp below that of the low voltage power supply. The blocking rectifier **48** now passes operating current from the low-voltage power source through the lamp electrodes. The current-limiting resistor R_5 connected in series with capacitor C_2 limits the amount of power dissipation from the capacitor C_2, and in conjunction with the inductance of the wiring to the lamp, prevents oscillatory discharge of the capacitor. The lamp now operates in its normal on condition with power supplied from the low-voltage power source.

In some cases, the switch **34**, lead **14**, and resistors R_1 and R_2 are omitted. The first electrode **12** of the lamp is connected directly to the positive terminal **36** of the low-voltage power source. The lamp ionizes at a voltage below the Zener breakdown voltage of the blocking rectifier **48**. The voltage across capacitor C_2 builds up until it exceeds the breakdown voltage of the lamp. At this point, the lamp voltage drops sharply, allowing discharge of sufficient energy from capacitor C_2 to cause the ionization in the lamp to become an arc. This further reduces the voltage drop across the lamp and permits power to be supplied directly from the low-voltage power source.

For general application, this latter mode of operation is not preferred, for two reasons:

A. The cost of the circuit is increased because a blocking rectifier of increased voltage rating must be used;

B. Often, mercury or other metals cause a low resistance leakage path across the lamp electrodes as they cool. The energy stored in the capacitor C_2 can be used to break down such a path by the operation of switch **34**.

An advantage of the starting circuit of this invention is that the use of a relatively large filter capacity in the position of capacitor C_1, causes the lamp to remain operating even if there is an intermittent power failure, say due to the starting of an elevator motor or other large piece of electrical equipment connected on the line. The reason for this is that the lamp electrodes stay hot enough to emit electrons, once fully heated, even after power is interrupted intermittently. The high voltage supplied through resistors R_1 and R_2 maintains ionization while these electrons are emitted, even when the lamp is so hot, and therefore at such a high internal pressure, that it would not be otherwise ionized. Prior art starting circuits must allow the lamp to cool for 5 to 10 minutes before they can be restarted.

I claim:

1. A starting circuit for a lamp having first and second electrodes, the circuit comprising a first electric power source having a pair of terminals, means connecting the terminals of the first source across the electrodes, a second electric power source of variable voltage lower than the first source and having a pair of terminals, a first circuit branch connected at one end to one of the terminals of the second source, means for connecting the other terminal of the second source to the second electrode, a second circuit branch of variable impedance connected in parallel with the first branch, a rectifier, means connecting adjacent ends of the two circuit branches remote from the said one terminal of the second source in series with the rectifier and the first electrode, a capacitor connected across the electrodes, means for sensing variations in the voltage of the second source, and means for automatically changing the impedance of the second branch in response to the sensing means to keep substantially constant the power delivered to the lamp from the second source.

2. A circuit for a lamp having first and second electrodes, the circuit comprising a first source of voltage having a pair of terminals, a first resistor, means connecting the first voltage source terminals and first resistor in series with the lamp electrodes, a second source of variable voltage having first and second terminals, a second resistor, a rectifier, means connecting the second resistor and rectifier in series with the first terminal of the second source, means for connecting the second terminal of the second source to the second electrode, a third resistor, a current control device connected in series with the third resistor, the third resistor and current control device being connected in parallel with the second resistor, a fourth resistor connected at one end to the end of the third resistor nearer the first electrode and at its other end to the second terminal of the second source, sensing means having an output and a pair of inputs, the inputs being connected to sense voltage variations between the first terminal of the second source and an intermediate position on the fourth resistor to develop a control signal at the output, means for automatically changing the current through the control device in response to the control signal from the sensing means to keep the power delivered to the electrodes from the second source substantially constant, a capacitor, a fifth resistor connected in series with the capacitor, and switch means for connecting the capacitor and fifth resistor across the electrodes, and for connecting the first terminal of the second source, the rectifier, and the second resistor in series with the first electrode.

3. A starting circuit for a pair of electrodes, the circuit comprising a first source of electric power having a pair of terminals, a first resistance connected in series with the electrodes and terminals of the first source, a capacitor and a second resistor connected together in series and in parallel with the first resistor and the electrodes, switching means for connecting the capacitor across the electrodes to bypass the second resistor and discharge the capacitor across the electrodes, a second source of electric power having a pair of terminals, a blocking rectifier, and means connecting the blocking rectifier and terminals of the second source in series across the capacitor so when the switching means is operated to discharge the capacitor across the electrodes, the second source is connected across the electrodes.

4. A circuit for a pair of electrodes, the circuit comprising a first source of voltage having a pair of terminals, a first resistance connected in series with the electrodes and terminals of the first source, a capacitor and a second resistor connected in series with each other and in parallel with the first resistor and the electrodes, switching means for connecting the capacitor across the electrodes to bypass the second resistor and discharge the capacitor across the electrodes, a second source of variable voltage having a pair of terminals, a third resistor, a blocking rectifier, means connecting the blocking rectifier, third resistor, and terminals of the second variable source in series across the capacitor so when the switching means is operated to discharge the capacitor across the electrodes, the second source is connected across the

electrodes, a current control device connected in parallel with the third resistor, a fourth resistor connected across the capacitor, sensing means having an output and a pair of inputs, the inputs being connected to sense voltage variations across the third resistor and a portion of the fourth resistor to develop a control signal at the output, the output of the sensing means being connected to change automatically the current through the current control device in response to the control signal to keep the power delivered to the electrodes from the second source substantially constant.

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