United States Patent [19]

Gerhard et al.

[11] **4,253,046**

[45] *** Feb. 24, 1981**

[54] **VARIABLE INTENSITY CONTROL APPARATUS FOR OPERATING A GAS DISCHARGE LAMP**

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[73] Assignee: **Datapower, Inc.,** Santa Ana, Calif.

[*] Notice: The portion of the term of this patent subsequent to Sep. 18, 1996, has been disclaimed.

[21] Appl. No.: **968,372**

[22] Filed: **Dec. 11, 1978**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 865,209, Dec. 28, 1977, Pat. No. 4,168,453, and a continuation-in-part of Ser. No. 940,435, Sep. 7, 1978.

[51] **Int. Cl.**^{3} **H05B 41/36**

[52] **U.S. Cl.** **315/224;** 315/105; 315/276; 315/307; 315/335; 315/DIG. 7

[58] **Field of Search** .... 315/105, 208, 209 R, 315/219, 224, 276, 291, 307, 311, 335, DIG. 4, DIG. 7

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,619,713	11/1971	Biega	315/DIG. 7
3,906,302	9/1975	Wijsboom	315/289 X
4,168,453	9/1979	Gerhard et al.	315/291 X

Primary Examiner—Eugene R. LaRoche
Attorney, Agent, or Firm—Knobbe, Martens, Olson, Hubbard & Bear

[57] **ABSTRACT**

A gas discharge lamp is connected across a step down auto transformer and in series with a solid state switching device and a resistor, and this combination is connected across a rectified AC voltage source. This switching device is controlled by a monostable multivibrator, the input of which is connected to the output of a comparator amplifier sensing the difference between the voltage drop across the above-mentioned resistor and a voltage which may be selected to vary light intensity. A starter aid conductor is placed adjacent the lamp and connected to the grounded side of the voltage source. This results in an efficient, high frequency operation of the lamp wherein the voltage gradient inside the lamp during starting ignition of the lamp is greatly increased to facilitate ignition despite the presence of the step down auto transformer, thereby permitting a decrease in the minimum fly back voltage necessary to start the lamp. As a result, reliability is increased.

11 Claims, 9 Drawing Figures

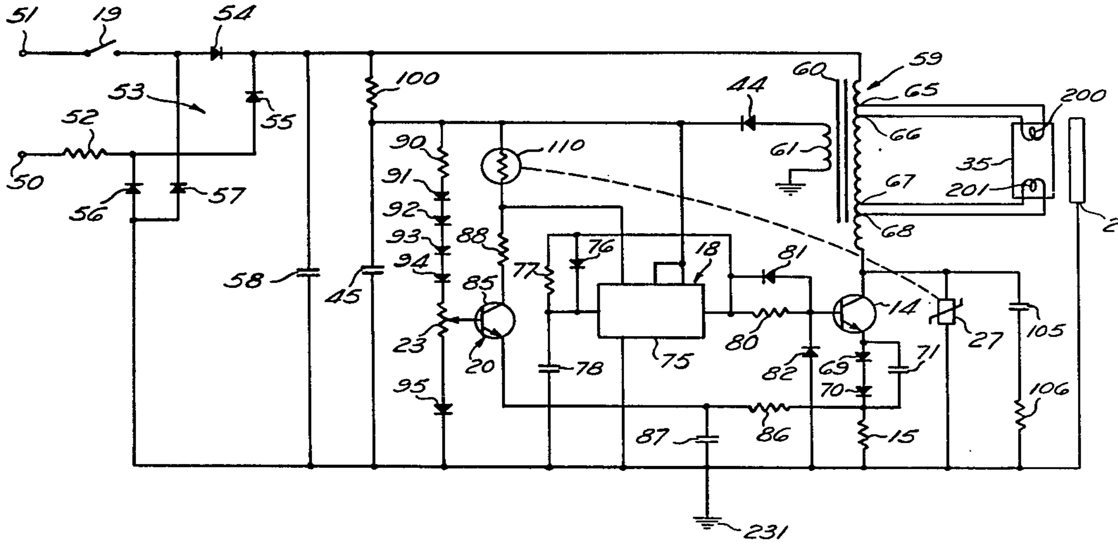

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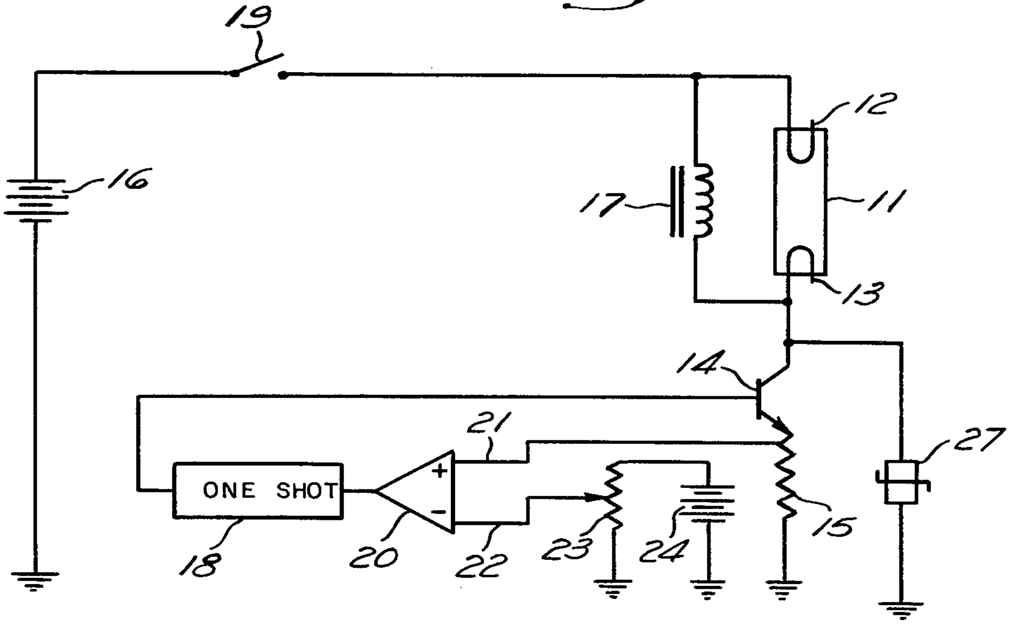
Fig. 1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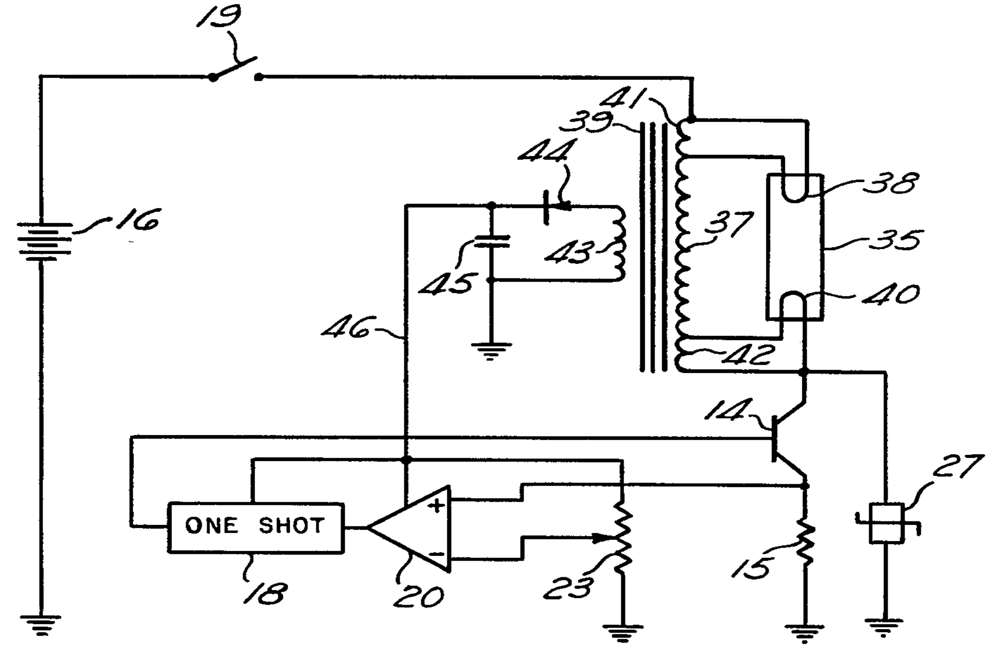
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Fig. 3

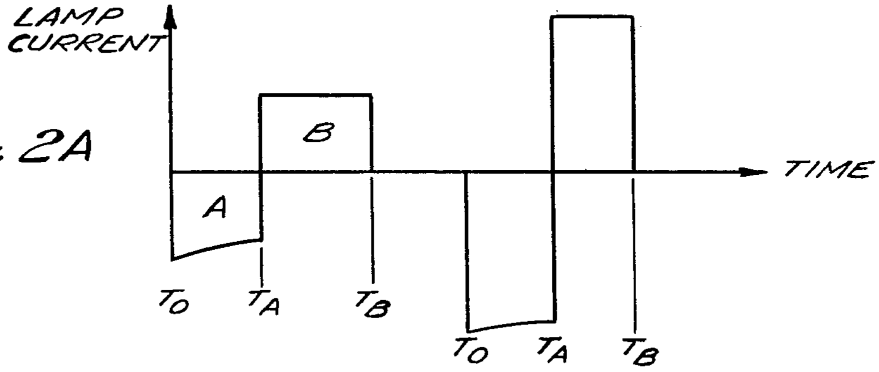

Fig. 2A

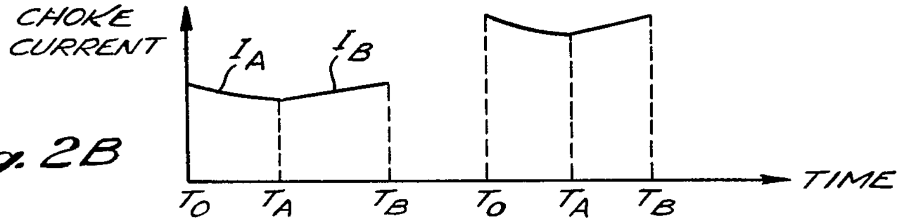

Fig. 2B

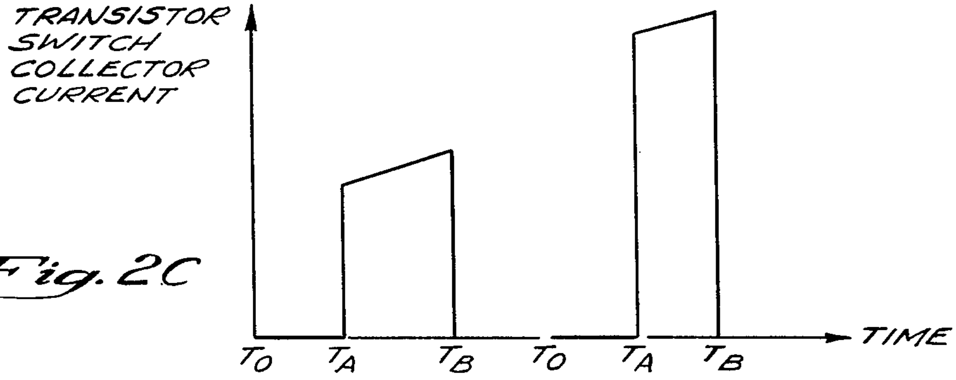

Fig. 2C

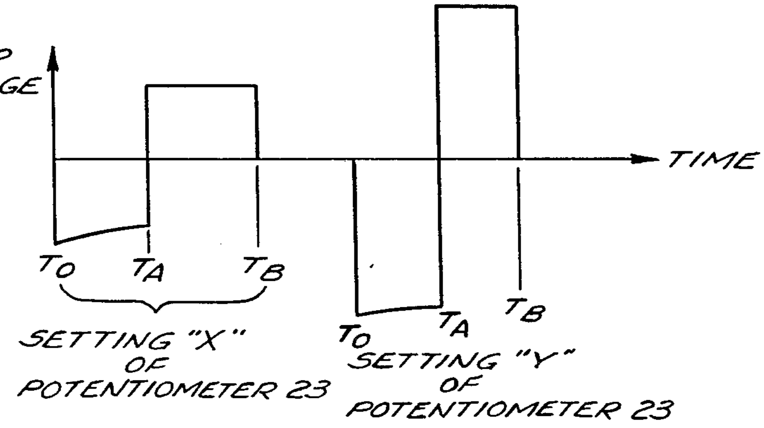

Fig. 2D

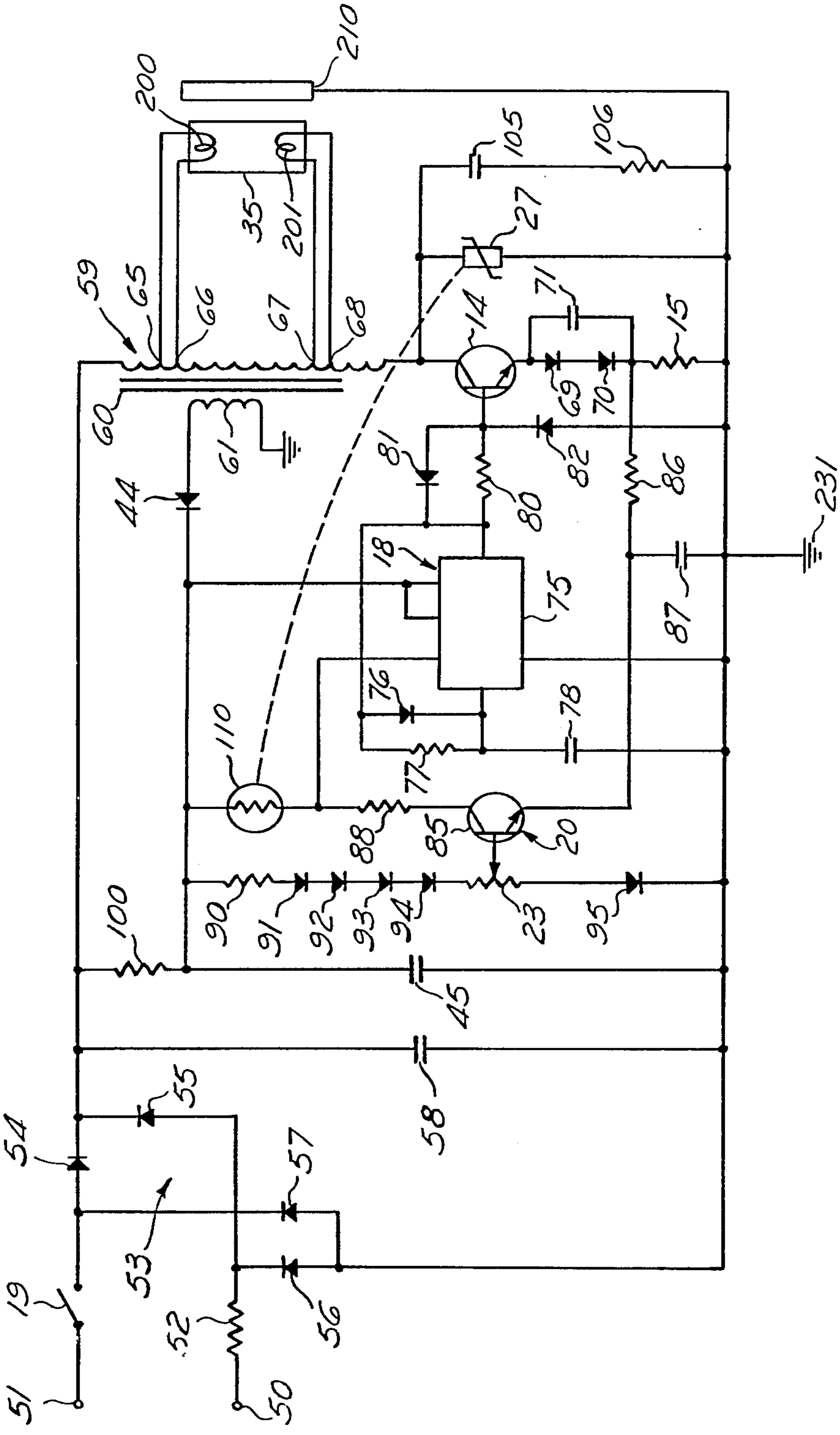
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Fig. 4

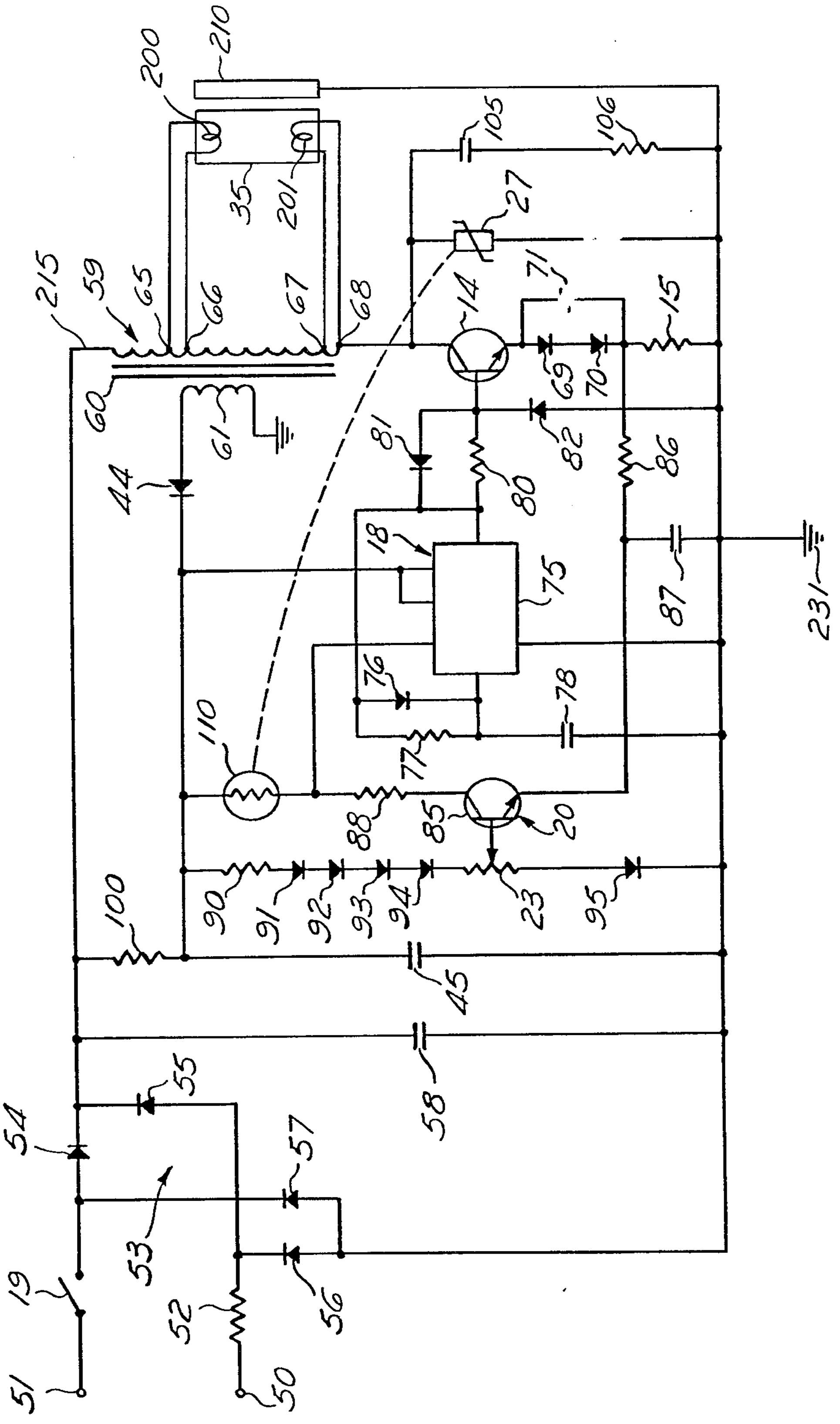

Fig. 5

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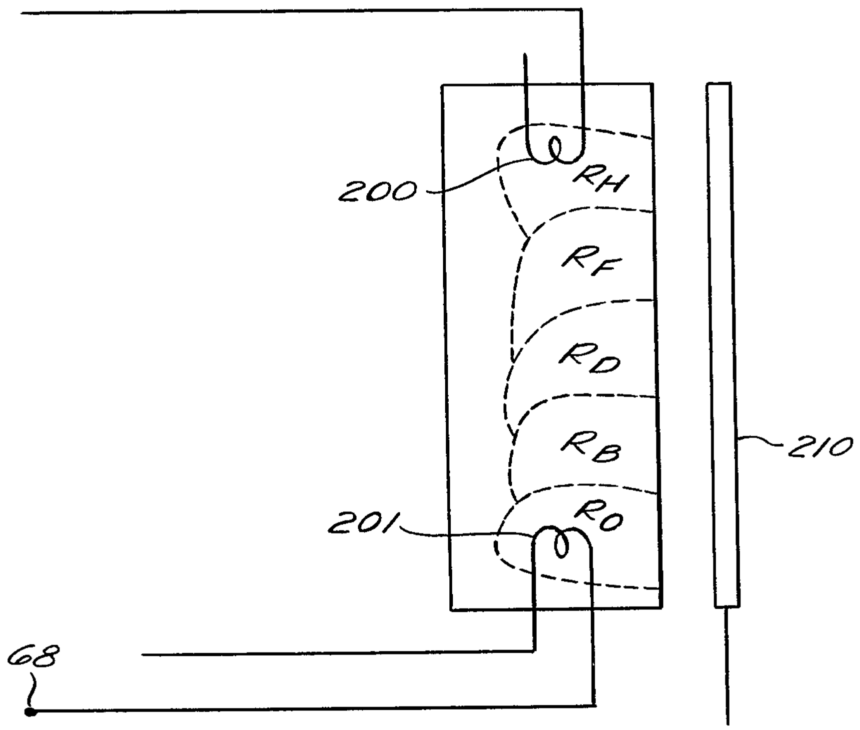
Fig. 6



VARIABLE INTENSITY CONTROL APPARATUS FOR OPERATING A GAS DISCHARGE LAMP

RELATED APPLICATION

This is a continuation-in-part of our co-pending application, Ser. No. 865,209, filed Dec. 28, 1977, U.S. Pat. No. 4,168,453, issued Sept. 18, 1979 and a companion case to an additional continuation-in-part of the same parent application, namely Ser. No. 940,435, filed Sept. 7, 1978.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus for operating a gas discharge lamp, such as a fluorescent light, a mercury vapor lamp, a sodium lamp, or a metal halide lamp.

2. Description of the Prior Art

Control circuits for gas discharge lamps are known which obviate the need for the usual heavy and expensive series ballast devices, corresponding to the inductor in this device. In such circuits, switching elements are provided to periodically reverse the direction of current through the lamp to reduce the deterioration or errosion of electrodes, and to ensure a high enough frequency of switching to reduce the requirement for the size of the ballast. Such circuits generally require two switching elements for each direction of the current.

Attempts have been made to fabricate the same type of circuit using only a single switching element to cause current reversal in the lamp. For example, the patent to D. B. Wijsboom, U.S. Pat. No. 3,906,302, is directed to such an arrangement and incorporates an inductor in parallel with the lamp, which lamp is in series with a switching device. Such a switching device is generally operated at relatively high frequencies, such as 20 kHz.

One problem has been that the fly back voltage during current reversal required to ignite the lamp when the circuit is first activated must be large enough to generate a sufficiently strong voltage gradient in the lamp to ionize the gas. This causes a large voltage to appear across the switching device which can damage the device during ignition, thereby limiting the reliability of the control circuit.

Another problem has been that it is often necessary to reduce the voltage supplied to the circuit in order to ensure that only the optimum lamp voltage is supplied to the lamp. It has been found that such a reduction in supply voltage decreases the voltage gradient in the lamp for starting ignition of the lamp during current reversal. Therefore, with the introduction of a step down auto transformer, the fly back voltage of the circuit must be increased to provide a sufficient voltage gradient in the lamp. Such an increase in fly back voltage increases the wear in components in the circuit and a consequent loss of reliability.

SUMMARY OF THE INVENTION

One electrode of a gas discharge lamp is connected to the tapped output of a step down auto transformer. One end of the auto transformer is connected to a rectified power source and the other end is connected to the collector of a transistor switch and to the other electrode of the gas discharge lamp. The emitter of the transistor is connected to one end of a resistor, and the other end of the resistor is connected to the AC power supply return. The base of the transistor is connected to

the output of a monostable or one-shot multivibrator. The input to the one-shot multivibrator is connected to the output of a comparator amplifier. The multivibrator operates in such a way that when the input to the multivibrator is high, the multivibrator is triggered and its output goes low for a predetermined amount of time, after which its output returns to the high state. The two inputs to the comparator amplifier are connected in such a way that one input is connected to the emitter of the transistor and the other input is connected to a voltage source which may be varied or controlled. The circuit components and the time delay of the multivibrator are chosen in such a way as to provide a relatively high rate of switching on the base of the transistor, approximately 20 to 40 kHz. A starter aid conductor is mounted adjacent the lamp and connected to the power supply return.

A significant feature of this invention is that the voltage gradient in the lamp during ignition may be maximized without regard to the step down ratio of the auto transformer, while the fly back voltage required for lamp ignition may be decreased. This reduces the fly back voltage across the transistor and therefore enhances the reliability of the circuit, while permitting the use of an auto transformer with any desired step down ratio.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in detail with reference to the accompanying drawings in which:

FIG. 1 illustrates an embodiment of a control circuit for a gas discharge lamp shown in simplified form for facilitating an understanding of the overall function of the control apparatus;

FIG. 2 shows four waveform plots labeled 2A, 2B, 2C, and 2D which are characteristic of the control circuit illustrated in FIG. 1. FIG. 2A is a plot of the current through the gas discharge lamp as a function of time, FIG. 2B is a plot of the current through the choke or inductor as a function of time, FIG. 2C is a plot of the collector current of the transistor as a function of time, and FIG. 2D is a plot of the voltage across the gas discharge lamp as a function of time. In all of these plots, time is plotted on the horizontal axis and the voltage or current is plotted on the vertical axis;

FIG. 3 illustrates a modified form of the control circuit of FIG. 1 in which the choke or inductor windings are used as the primary windings of a step down transformer which supplies power for the one-shot multivibrator and the comparator amplifier as well as the reference voltage to the input of the comparator amplifier. FIG. 3 also illustrates the use of the primary coil as an auto transformer to supply current to the electrodes of the gas discharge lamp as a source of preheating current prior to ignition of the lamp;

FIG. 4 illustrates a detailed circuit schematic including provision for (a) a step down voltage supply to the lamp for matching the line voltage to the optimal lamp operating voltage and (b) a starting aid adjacent the gas discharge lamp;

FIG. 5 illustrates the preferred embodiment of this invention in which the connection of the gas discharge lamp and the connection of the starter aid maximizes the starting voltage supplied to the lamp; and

FIG. 6 is a schematic illustration of the progressive ionization of the gas in the gas discharge lamp during start up.

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DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the circuit illustrated in FIG. **1**, a gas discharge lamp **11**, typically a low-pressure mercury vapor fluorescent lamp, having two electrodes **12** and **13**, has its electrode **13** connected to an electronic switch shown as an NPN transistor **14**, the collector of which is connected to electrode **13**, and the emitter connected to a resistor **15**. The other end of the resistor **15** is connected to ground. The other electrode of the gas discharge tube **12** is connected to a DC power supply. This supply will normally be a rectified AC source but is shown for simplicity in this figure as a battery **16** whose positive terminal is connected through on-off switch **19** to electrode **12** and whose negative terminal is connected to ground. A choke or inductor **17** is connected in parallel with the electrodes of the gas discharge lamp **12** and **13**.

The base of the NPN transistor switch **14** is connected to the output of a one shot multivibrator **18**. The monostable multivibrator operates in such a way that when the input to the multivibrator is low its output is high, and when its input is high, the monostable multivibrator is triggered such that its output goes into the low state for a predetermined finite length of time, after which the output of the multivibrator returns to the high state. The input of the multivibrator is connected to the output of a comparator amplifier **20**. The positive input of the comparator amplifier is connected through a conductor **21** to the emitter of the NPN transistor **14**, and the negative input of the comparator amplifier is connected through a conductor **22** to a potentiometer **23**. Potentiometer **23** is connected to the positive end of a DC power source **24**, and the negative end of the DC power source **24** is connected to ground.

The operation of the circuit of FIG. **1** is as follows. When the switch **19** is first closed, the current passes through the switch **19** and through the inductor **17**. No current passes through the gas discharge lamp **11** because, until it is ignited by high voltage, the lamp remains nonconductive. The current through the inductor passes through the NPN transistor switch **14** and through the resistor **15** to ground. The current through the inductor **17** rises as a function of time until it reaches a level at which the voltage drop across the resistor **15** exceeds the voltage on the conductor **22**. The voltage on the conductor **22** is determined by the potentiometer **23**. When the voltage drop across the resistor **15** exceeds the voltage on the conductor **22**, the comparator amplifier **20** senses a positive difference between its inputs and the output of the comparator amplifier **20** changes from the low to the high state. In response to the high output of the comparator amplifier **20**, the one shot multivibrator **18**, is triggered and provides a low output for a short predetermined length of time. Thus, the transistor switch **14** will be turned off for the short period of time during which the base of the transistor receives a low level signal from the multivibrator **18**. The magnetic field in the choke **17** then collapses, resulting in a fly back voltage potential across the electrodes **12** and **13** of the gas discharge lamp **11**. This potential is sufficient to ignite the lamp and the lamp begins to conduct current. The fly back voltage is also applied to the collector of the transistor **14**.

After the above-mentioned short predetermined length of time, the one shot multivibrator output returns to its normally high level state, thereby turning the transistor switch **14** back on. At this instance in time, current begins to flow from the source **16** through the electrodes **12** and **13** of the gas discharge lamp **11** in the opposite direction to the current supplied before by the choke **17**. The magnetic field in the choke **17** also begins to build up again as does the current through the choke **17**. This results in a rise in the collector current of the transistor **14** and an equal rise in current through the resistor **15**. This rise in current will cause the voltage drop across resistor **15** to rise until the conductor **21** again exceeds the voltage on conductor **22**. Again, the comparator amplifier **20** will give a high output when this condition is reached, causing the output of the multivibrator **18** to go into the low state for the finite period of time thereby turning off the collector current of the transistor **14**. The magnetic field in the choke **17** will collapse at this time, thereby causing a current to flow between the electrodes **12** and **13** of the gas discharge lamp **11** in a direction opposite to the direction traveled by the current when the transistor **14** was on. This condition will continue until the multivibrator output remains automatically to the high state.

As may be seen from this description, this process will continue to repeat itself as the transistor **14** continuously is switched on and off until steady state conditions are achieved. One or more cycles of operation may be required to ionize the lamp and cuase it to ignite.

A varistor or high voltage zener diode **27** is connected between the collector of the NPN transistor and ground, and serves to protect the transistor **14** from destructive breakdown in the event of lamp failure causing an open circuit between its terminals, or inadvertent unplugging of the lamp when the power switch **19** is closed. When the lamp itself is defective and causes an open circuit or when the lamp is removed, the voltage rise at the collector of transistor **14** produced by collapse of the magnetic field in the inductor **17** will be limited to the breakdown voltage of the varistor, a value selected to be within the safe limits of the collector-base junction of the transistor switch **14**.

A significant feature of the invention is that the varistor **27** serves the additional function of preventing ignition of the lamp until the lamp electrodes have been warmed up over a time period which is long compared to the operating period of the control circuit. Thus, the control circuits of this invention, without the varistor, would typically supply on the order of 1000 volts across the lamp in the fly back mode. Such high voltage applied to the lamp filaments when they are cold would be extremely deleterious since the electrodes would undergo a very high rate of change of temperature. The varistor is selected such that it breaks down for voltages exceeding 500 to 600 volts. At these lower voltages, the lamp **11** will not ignite until after the cathodes have been heated. Typically, a time delay of ¾ second to one second is the amount of time needed to heat up the cathodes sufficiently for the lamp to ignite when supplied with 500 to 600 volts.

FIGS. 2A, 2B, 2C, and 2D are plots of the steady state response characteristics of the circuit for two different levels of input power to the gas discharge lamp.

FIG. 2A is a plot of a single cycle of current through the gas discharge lamp as a function of time. The current is plotted on the vertical axis and the time is plotted on the horizontal axis. It will be understood that the current alternates through the lamp in a repetitive cycle. In the region of FIG. 2A, denoted "A", the transistor switch **14** is in the off state and the collapsing field in the inductor **17** is forcing a current through the gas discharge lamp. The region A covers a period of time between time T_O and time T_A. This time period is equal to the unstable period of multivibrator **18**. In the region in FIG. **2A** denoted "B", the transistor switch **14** is on. The region B lies between the time T_A and the time T_B, after which the cycle repeats itself.

In FIG. 2A, the magnitude of the lamp current in region A is shown to be roughly equal to the magnitude of the current in region B. Since, for reasons described above, there is no net DC current through the lamp, the respective areas under the curves in regions A and B are equal. Thus, in the circuit operating mode illustrated by FIG. 2A, the duration of the time periods A and B are roughly equal. The operational mode shown in FIG. 3A having approximately equal current flows in regions A and B is advantageous since it maximizes the efficiency of the lamp and also minimizes the current handling requirements for the switch transistor **14**. This operating mode is achieved for a fairly narrow range of DC voltage output of the power source **16** for a given lamp. The circuit of FIG. **4** described below provides a means for matching a given DC voltage to a plurality of lamp or lamps having different optimum voltages.

FIG. 2B is a lot of the current through the choke or inductor **17** as a function of time. The current through the choke is plotted on the vertical axis, while time is plotted on the horizontal axis. In the region of FIG. 2B denoted "A", at time T_O, the transistor has been turned off and the current through the choke is decaying as a function of time until time T_A. At time T_A, the transistor is turned on. The current through the choke in the region of FIG. 2B denoted "B" increases until time T_B, at which time the transistor is turned back off, and the cycle repeats itself. The behavior of the circuit thus alternates between the behavior plotted in region A and the behavior plotted in region B.

FIG. 2C is the plot of the collector current of the transistor plotted as a function of time. The collector current amplitude is plotted on the vertical axis and time is plotted on the horizontal axis. In the region denoted A of FIG. 2C, the transistor is off and therefore the collector current remains zero, from time T_O to the end of region A at time T_A. In the region denoted B in FIG. 2C, at time T_A, the transistor is turned on and remains on until time T_B, which defines the end of region B. During this time, the collector current continually increases. At time T_B the transistor is again turned off and the process repeats itself. Thus, the collector current is periodic in time. The current level indicated by the plot is equal to the voltage on the conductor **22** of FIG. **1** divided by the resistance of the resistor **15** in FIG. **1**.

FIG. 2D is a plot of the voltage across the gas discharge lamp as a function of time. It is identical in shape to the lamp current shown in FIG. 2A at the operating frequency of the circuit, i.e., the frequency at which the transistor switch **14** is switched on and off. This frequency is chosen so that its period is short compared to the ionization time of the lamp. A representative operating range is from between 20 to 40 kHz. At this high frequency, the lamp appears electrically to be a resistor. Since the current through a resistor is linearly proportioned to the voltage across it, the lamp voltage and current waveforms are identical in shape.

This high frequency operation has the significant advantage that the weight of the choke, shown in FIG. **1** as **17**, may be considerably reduced below the weight of the typical chokes found in the usual fluorescent lamp circuits using 60 Hz AC sources. By way of specific example, a choke suitable for use at 20 kHz will weigh on the order of 4 or 5 ounces whereas the corresponding choke for use at 60 Hz will weigh 4 or 5 pounds.

A feature of the invention is that a selectively variable control over lamp intensity may be provided by the potentiometer **23**. The power input to the lamp (and the resultant lamp intensity) are approximately proportional to the average magnitude of the lamp current, which is plotted in FIG. 2A. This plot shows the current reversal during periods when the transistor is turned off, which occurs, for example, at time T_B.

Assume that at a particlar setting "X" of the potentiometer **23** in FIG. **1**, the voltage on conductor **22** in FIG. **1** is lower than the voltage on the conductor at another setting "Y" of the potentiometer **23**. The corresponding changes in the waveforms in FIGS. 2A, 2B, 2C, and 2D between the two settings of the variable resistor for effecting different levels of the lamp intensity are illustrated in these figures. In each figure, the waveform on the left represents setting X and the waveform on the right in each figure represents setting Y.

The manner in which this ocntrol is achieved with potentiometer **23** is as follows.

The peak lamp current always occurs whenever the transistor is turned off, corresponding to times T_O and T_B. This occurs whenever the sum of the choke current and lamp current passing through the resistor, denoted **15** in FIG. **1**, causes a voltage drop across this resistor equal to the voltage on the conductor, denoted **22** in FIG. **1**. As stated above, this occurrence causes the comparator amplifier, **20** in FIG. **1**, to give a positive output to the multivibrator, which in turn causes the multivibrator to turn the transistor off.

The current passing through the resistor, **15** in FIG. **1**, is the collector current of the transistor. This current is plotted in FIG. 2C, as the sum of the lamp current and choke current in region B.

The peak collector current level is equal to the voltage on the conductor **22** in FIG. **1** divided by the resistance of the resistor, **15** in FIG. **1**. When the voltage on the conductor **22** is increased or decreased, the collector current peak level will increase or decrease, respectively. Because the decay time of the current between time T_O and time T_A is always the same, the minimum value of the collector current will also increase or decrease, respectively. Thus, the entire waveform of the collector current will be shifted either up or down, respectively, of which two exemplary waveforms are plotted for the two different potentiometer settings X and Y. The waveforms of the choke current and the lamp current will also be shifted up or down, respectively, as shown. This effect is the result of the fact that the collector current through the transistor is the sum of the choke current and lamp current, and the fact that the lamp current is proportional to the choke current.

Thus, it may be seen that the lamp intensity, which is proportional to lamp current, is proportional to the voltage on the conductor **22**. By changing the resistance of the potentiometer **23** in FIG. **1**, the current supplied to the lamp **11** will change.

The useful life of the gas discharge lamp is increased in this invention since the net DC component of current through the lamp during continued operation is approximately zero. This is achieved by virtue of the parallel inductance which has the property of maintaining a

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zero DC voltage drop across its terminals. Since this zero DC voltage is also maintained across the lamp, the DC current through the lamp will also be zero.

Although the circuit is particularly suited for use with low intensity, low pressure mercury vapor fluorescent lamps, it can equally well be used to control various other types of gas discharge lamps such as high pressure mercury vapor, high or low pressure sodium, and metal Halide lamps.

FIG. **3** illustrates a modified embodiment of the invention in which a gas discharge lamp **35**, typically a low pressure mercury vapor fluorescent lamp of approximately 22 watts, is provided. The electrodes **38** and **40** are of the heated type. Power is derived from a DC voltage source **16**.

An inductor **37** is connected in series with the transistor **14** and resistor **15** across the power supply **36**. The electrodes **38** and **40** of lamps **35** are tapped into sections **41** and **42** of the winding of inductor **37** to preheat such electrodes prior to ignition of the lamp.

The inductor **37** also acts as the primary winding of a transformer and has an iron core **39** and a step-down secondary winding **43** associated therewith. The winding **43** is connected in circuit with a diode **44** across a capacitor **45**. The diode **44** is also connected through line **46** to the power input terminals of the comparator amplifier **20** and multivibrator **18**. It is also used to supply the reference voltage to the potentiometer **23**.

The sections **41** and **42** of the winding of inductor **37** enable the electrodes **38** and **40** to become heated before the lamp is ignited. This arrangement maximizes electrode life and prevents damage to the electrodes **38** and **40** due to the otherwise excessive rise of temperature at the start of a lamp operation.

The polarity of the winding **43** is preferably such that the capacitor **45** is charged only when the transistor **14** is conducting. This arrangement insures that the particular voltage on capacitor **45** is independent of the variable fly back voltage developed by the inductor **37** when the transistor **14** is cut off.

FIG. **4** illustrates a detailed circuit schematic showing a number of circuit elements which were deleted from the simplified circuits described above to facilitate understanding of the overall oepration of the invention. In addition, this figure illustrates several significant additional features of the invention.

The circuit of FIG. **4** is designed to operate from a standard 120-volt AC line connected to terminals **50** and **51**. These terminals respectively connect to on-off switch **19** and current limiting resistor **52** to a full-wave diode bridge rectifier **53** comprising diodes **54**, **55**, **56**, and **57**. The DC output of this rectifier is connected across a wave smoothing capacitor **58**. The negative bridge terminal is connected to ground and the positive bridge terminal is connected to one end of an autotransformer winding **59** having a magnetic core **60**, and secondary winding **61**.

In the illustration, winding **59** functions as a voltage reducing auto-transformer with one of the lamp electrodes connected to respective mid-taps **65** and **66** and the other lamp electrode connected to taps **67** and **68** located at the end of the winding. The purpose of the auto transformer is to match the DC power supply with the optimum voltage characteristic of the lamp. For example, the output of the diode bridge **53** is approximately 168 volts DC with 120-volt AC input. The optimum voltage for a 22-watt fluorescent lamp is, however, typically only 55 volts. Accordingly, the auto-transformer winding is selected so that the step-down turns ratio is 168 divided by 55. It will be understood that if the optimum lamp operating voltage is larger than the DC power source voltage, a step-up auto-transformer would advantageously be used to supply the stepped up voltage in the same manner.

The collector of NPN switch transistor **14** is connected to the end terminal **68** of the auto-transformer winding **59**. Its emitter is connected through a pair of diodes **69** and **70** and resistor **15** to ground. A capacitor **71** parallels the series connected diodes **69** and **70**. Capacitor **71** is charged during steady state operation such that the combination of the capacitor **71** and diodes **69** and **70** back bias the transistor emitter.

Integrated circuit **75**, diode **76**, resistor **77**, and capacitor **78** comprise one-shot multivibrator **18**. The power supply for this one-shot multivibrator is provided by the secondary winding **61**, diode **44**, and capacitor **45** as described above with reference to the circuit of FIG. **3**.

The base of transistor switch **14** is connected to the output of the one-shot multivibrator **18** through parallel connected resistor **80** and diode **81**. Resistor **80** serves as a base current limiting resistor and shunting diode **81** serves to short out this resistor and provide a low impedance path for the charge stored in transistor **14** when the transistor is turned off. The base is also connected to ground through diode **82**.

Comparator amplifier **20** comprises transistor **85** whose emitter is connected to the junction of diode **70** and resistor **15** through an RC filter comprising resistor **86** and capacitor **87**. Its base is connected to potentiometer **23** and its collector is connected to the input of one-shot multivibrator **18** through resistor **88**.

Potentiometer **23** is connected in series circuit with the resistor **90** and diodes **91**, **92**, **93**, **94**, and **95**. Resistor **90** reduces the sensitivity of potentiometer **23**. Diodes **91** through **94** protect the circuit against transients when the on-off switch **19** is initially closed and diode **95** compensates for the base-emitter drop of comparator transistor **20**. As in the embodiment of FIG. **3**, the reference voltage for potentiometer **23** is provided by the output of secondary winding **61**. The RC filter comprising resistor **86** and capacitor **87** serves to prevent a voltage or current transient from affecting comparator transistor **20** and inadvertently triggering the one-shot multivibrator **18**.

A resistive path directly connecting the positive terminal of the diode bridge **53** to the power supply provided by secondary winding **61** is provided by resistor **100**. This resistor serves as a current bleeder resistor to provide start-up power when the on-off switch **19** is initially closed.

Capacitor **105** and resistor **106** function in parallel with varistor **27** as a snubber protective circuit for protecting the transistor **14** from the inductive auto-transformer load when the transistor is being turned off.

Another significant feature of the circuit of FIG. **4** is the inclusion of thermistor **110** electrically connected between the input of one-shot multivibrator **18** and the positive side of the power supply capacitor **45**. The thermistor is mechanically and thermally attached to the varistor **27** as indicated by the dotted line. The varistor has a negative temperature coefficient selected such that when a transient surge in the circuit causes the varistor to begin to overheat, the thermistor will become highly conductive and act to hold the input of the one-shot multivibrator high, thereby maintaining the transistor **14** in the off state. Thus, the circuit illustrated in FIG. **4** will remain effectively shut down until such time as the varistor **27** has a chance to cool. Accordingly, it will be seen that thermistor **48** prevents overheating of the varistor **27**.

An exemplary circuit for operation of a 22-watt fluorescent lamp from 120-volt AC power in accordance with FIG. **4** has the following circuit components:

Transistor 14	MJE 13004 (Motorola)
Resistor 15	2.2 ohm
Potentiometer 23	200 ohm
Varistor 27	V275LA 20 (General Electric)
Resistor 52	1.5 ohm
Diodes 54-57	IN4003
Capacitor 58	100 Micro farad
Winding 59	263 + 6 + 150 + 6 turns
Core 60	Ferroxcube 376U250-3c8 and 376B250-3c8
Winding 61	41 Turns
Diodes 69, 70, 76, 81, 82, 91-95	IN4148
Capacitor 71	10 Micro farad
Integrated Circuit 75	NE 555 V
Resistor 77	10K ohm
Capacitor 78	.0033 Micro farad
Resistor 80	200 ohm
Transistor 85	2N 3904
Resistor 86	22 ohm
Capacitor 87	.1 Micro farad
Resistor 90	1.3K ohm
Resistor 100	20K ohm
Capacitor 105	560 Pico farad
Resistor 106	220 ohm
Thermistor 110	4C5002 (Western Thermistor)

In the circuit of FIG. **4**, the fly back voltage across the electrodes **200,201** caused by switching the transistor **14** off must be sufficiently high to light the lamp when the switch **19** is first closed. The voltage occurring in the circuit when the transistor **14** is first turned off, corresponding to time T_B in FIG. **2***a*, will be referred to as the fly back voltage. Ignition of the lamp requires that the fly back voltage between the two electrodes **200,201** in the lamp **35** be sufficiently high, and the distance between the electrodes **200,201** be sufficiently small so that the resulting voltage gradient in the lamp **35** has sufficient magnitude to cause the gas inside the lamp **35** to ionize. The term "voltage gradient" is understood to be the voltage drop per unit distance. It is well known that, for a gas which may be used in a gas discharge lamp, there is a threshold voltage gradient below which ionization of the gas cannot be achieved.

The voltage gradient near the electrode **201** at ignition of the lamp is proportional to the fly back voltage across the two electrodes **200,201** divided by the distance between the electrodes **200,201**. The large fly back voltages which are typically required may have deliterious effects upon the transistor **14**, and therefore upon the reliability of the circuit of FIG. **4**. It is this concern for the reliability of the circuit of FIG. **4** that prompts the use of varister **27**, the thermister **110**, and the capacitor **105**.

As mentioned above, it is well known that commercially available gas discharge lamps operate most efficiently at a certain optimum supply voltage. In order to match the line voltage with this optimum lamp voltage, an auto transformer may be used as shown in FIG. **4**. The auto transformer **59** has a step down ratio which is proportional to the number of turns in the winding of the auto transformer **59** between the taps **66** and **67** divided by the total number of turns in the entire winding.

Introduction of the auto transformer **59** causes a reduction in the fly back voltage between the electrodes **200,201**. Therefore, in order to provide a threshold voltage gradient in the lamp **35** sufficient to ignite the lamp when the switch **19** is first closed, the fly back voltage must be increased. This increase in fly back voltage may be achieved by increasing the breakdown voltage of the varistor **27**. Otherwise, when the switch **19** is closed, the lamp **35** may not ignite. This increase in fly back voltage, however, increases the likelihood of harm to the transistor **14** and decreases the reliability of the circuit of FIG. **4**.

In this invention, these difficulties are overcome by connecting a starter aid **210**, as shown in FIG. **4** to ground **231**, and locating the starter aid **210** adjacent the lamp **35**. The starter aid **210** is merely an elongate conductor which is preferably mounted parallel to and within one inch of the lamp **35**. It may, for example, be a thin strip of metal mounted on the outside of the lamp **35**.

The starting aid **210** acts to increase the voltage gradient near the electrode **201** when the transistor **14** is first opened to produce a fly back voltage in the circuit. Because this fly back voltage is the largest voltage in the circuit, it is used to ignite the lamp. In the absence of the starter aid conductor **210**, the voltage gradient created in the lamp by the fly back voltage is inversely proportional to the distance between the electrodes **200** and **201**. However, when the starter aid conductor **210** is connected to ground **231** and held adjacent to the lamp **35**, it provides a voltage gradient between the electrode **201** and the starting aid conductor **210**. This voltage gradient is much larger than the voltage gradient created in the absence of the starter aid conductor **210** between the electrode **201** and the electrode **200** because the distance between the electrode **201** and the starting aid conductor **210** is much less than the distance between the electrode **201** and the electrode **200**.

When the switch **19** is closed, the transistor **14** is first closed and then opens to cause the fly back voltage in the manner described earlier in this specification. The fly back voltage between the terminal **68** and ground **231** results in a large voltage gradient between the electrode **201** and the starter aid conductor **210**. Of course, another voltage gradient will appear between the electrode **200** and the starter aid conductor **210**, but because the fly back voltage at the electrode **200** is reduced by the step down transformer **59**, the voltage gradient in the vicinity of the electrode **201** is larger.

Preferably, the maximum voltage gradient which appears at the electrode **201** is just sufficient to ionize the gas in the vicinity of the electrode **201**. However, because this maximum voltage gradient is restricted to a limited vicinity around the electrode **201**, ionization will occur in this limited area only. However, during subsequent operation of the circuit, the vicinity of ionization will progressively expand, as best illustrated in FIG. **6**. Assuming that the transistor **14** has opened to cause the fly back voltage at time T_O of FIG. **2***a*, the transistor will again close at time T_A and the fly back voltage will disappear. The transistor again opens at time T_B and a fly back voltage again appears. The ionized gas which was created by the first fly back voltage at time T_O does not totally deionize between T_A and time T_B, the interval between fly back voltages, but substantially remains in the vicinity of the electrode **201**, which is illustrated in FIG. **6** as the outlined region designated R_O. During the next fly back voltage at T_B,

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the ionized gas in the region R_O acts substantially as a conductor. Therefore, a large voltage gradient is created by the fly back voltage at time T_B and appears between the entire region R_O and the starter aid conductor **210**. This large voltage gradient is sufficient to cause further ionization, and this causes the region of ionization to expand from the smaller region R_O to the larger region R_B. Again, the cycle repeats itself, and this time the fly back voltage gradient appears between the conducting ionized gas in the expanded region R_B and the starter aid conductor **210**, which causes the region of ionized gas to further expand until it encompasses the region R_D.

It is seen that, through successive cycles, the region of ionized gas expands progressively, beginning in the smaller region R_O, then regions R_B, R_D, R_F, and finally encompasses the region R_H which includes the second electrode **200** and establishes a conducting ionized gas electrical current path between the electrodes **200** and **201**, at which time the ignition of the lamp **35** is complete. It may also be seen that the fly back voltage of the terminal **68** required to ignite the lamp may be relatively small to increase the reliability of the circuit.

It is significant that in the circuit of FIG. **4**, the location of the taps **65**, **66**, **67**, and **68** on the auto transformer **59** is arbitrary, and the electrodes **200,201** may be connected across any segment of the auto transformer **59** which gives the proper step down ratio without affecting the operation of the lamp **35** after ignition. For example, the lamp **35** may be connected across the top half of the auto transformer, or the lamp may be connected across the intermediate segment of the auto transformer **59**. However, as pointed above, the auto transformer **59** causes a reduction in the fly back voltage between the electrodes **200,201**. A similar reduction in fly back voltage between the electrode **201** and ground **231**, which generates the starting voltage gradient between the electrode **201** and the starter aid conductor **210**, is present in the circuit of FIG. **4** due to the step down auto transformer **59**. It is desirable to eliminate any reduction of the voltage between the electrode **201** and the conductor **210** by the auto transformer **59**, so that the voltage gradient near the electrode **201** may be maximized when the transistor **14** first opens to create a fly back voltage to ignite the lamp **35**.

The circuit of FIG. **5** eliminates any reduction of the voltage gradient between the electrode **201** and the conductor **210** by the auto transformer **59**. The operation of the circuit of FIG. **5** is similar to that of FIG. **4** except that the corresponding voltage gradient at the electrode **201** caused by the fly back voltage between the electrode **201** and the conductor **210** is maintained at the threshold level required for ignition without regard to the selection of the step down ratio of the auto transformer **59**. The electrode **201** in FIG. **5** is connected directly to rhw terminal **68** connecting the transistor **14** to the auto transformer **59** while the other electrode **200** is connected to a mid-tap on the auto transformer **59** such as the mid-tap **66**. Such a direct connection prevents the fly back voltage between the starter aid **210** and the electrode **201** from being reduced by the step down auto transformer **59**.

Unless the electrode **201** is connected to the collector of the transistor **14** as shown in FIG. **5** and the starter aid conductor **210** is used, the largest voltage gradient inside the lamp **35** at ignition is approximately proportional to the fly back voltage appearing across the terminal **68** and ground **231** reduced by the auto transformer **59** and divided by the relatively large distance between the electrodes **201,200**. It is now apparent that introduction of the starter aid conductor **210** permits a much smaller fly back voltage to be used which can nevertheless cause a sufficiently large voltage gradient between the electrode **201** and the starter aid conductor **210** to achieve ionization of the gas in the lamp **35** and ignition of the lamp when the switch **19** is first closed. Furthermore, through proper connection of the auto transformer to the lamp, as shown in FIG. **5**, an auto transformer of any step down ratio may be used without affecting this voltage gradient. It should be recognized that a step up auto transformer for increasing the voltage supplied to the lamp **35** may also be used in place of the step down auto transformer **59** of FIG. **5**.

What is claimed is:

1. A circuit for energizing a gas discharge lamp comprising:

first means for storing magnetic energy, said means connectable across a power source, at least a portion of said first means connected in parallel combination with the electrodes of said gas discharge lamp, the extent of said portion, in comparison with the overall storing means, defining a voltage transforming ratio;

second means for connecting a power supply to said parallel combination;

third means operatively coupled to said second means for interrupting the connection between said power supply and said parallel combination for a predetermined length of time whenever the current through said parallel combination has increased to a predetermined level; and

fourth external conductor means for increasing the voltage gradient inside said lamp during ignition of said gas discharge lamp independently of said voltage transforming ratio.

2. A circuit for energizing a gas discharge lamp, as defined in claim **1**, wherein:

said fourth external conductor means comprises a starter aid conductor adjacent one of said electrodes, said conductor grounded to one side of said power supply.

3. A circuit for energizing a gas discharge lamp as defined in claim **1** wherein said first means comprises a step down autotransformer.

4. Apparatus for energizing a gas discharge lamp having a pair of electrodes which comprises:

a voltage supply having two terminals;

a switching device;

a resistor;

an inductor having two connection ends;

means connecting said inductor, said switching device and said resistor in series across said two terminals, said switching device connected between said resistor and said inductor, said two terminals connected to said resistor and said inductor, respectively;

means connecting said pair of electrodes in parallel combination with at least a portion of said inductor;

a one-shot multivibrator having a first variable time output state and a second fixed time output state;

means connecting the output of said multivibrator to said switching device to close said switching device during said first output state and to open said switching device during said second output state;

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means for putting said multivibrator in said second state when the voltage across said resistor reaches a predetermined level; and

a starter aid conductor located adjacent said lamp, extending parallel to the gap between said two electrodes, said conductor connected to one of said terminals of said AC voltage supply.

5. An apparatus for energizing a gas discharge lamp, as defined in claim **4**, wherein:

said portion of said conductor which is connected in parallel combination with said pair of electrodes includes the end of said inductor which is connected to said switching device.

6. An apparatus for energizing a gas discharge lamp, as defined in claim **4**, wherein:

said starter aid conductor is connected to the terminal of said voltage supply which is connected to said resistor.

7. An apparatus for energizing a gas discharge lamp, as defined in claim **4**, wherein:

the distance between said two electrodes and said starter aid conductor is sufficiently small so that at least some of the gas in said gas discharge lamp is ionized whenever said multivibrator first enters said second state to open said switching device to ignite said lamp.

8. A circuit for energizing a gas discharge lamp comprising:

first means for storing magnetic energy, at least a portion of said first means connected in parallel combination with the electrodes of the gas discharge lamp;

second means for connecting a power supply to said parallel combination;

third means operatively coupled to said first and second means for interrupting the connection between said power supply and said parallel combination for a predetermined length of time whenever the current through said parallel combination has increased to a predetermined level;

fourth means for stepping down the voltage supplied to said electrodes by said power supply in a desired step down ratio; and

fifth means for providing an increase in the voltage gradient near one of said electrodes in said lamp when said lamp is initially ignited, said increase independent of the step down ratio of said fourth means.

9. A circuit for energizing a gas discharge lamp as defined in claim **8** wherein said fourth means comprises a center tap on said first means, said tap defining said portion of said first means, said center tap connected to one of said electrodes.

10. A circuit for energizing a gas discharge lamp as defined in claim **9** wherein said fifth means comprises a conductor adjacent said lamp and adjacent to at least the other of said electrodes, said conductor connected to said return of said power supply, and wherein the fifth means further comprises a connection between said other electrode and the junction between said third means and said first means so that said voltage gradient is unaffected by said fourth means.

11. A circuit for energizing a gas discharge lamp comprising:

a gas discharge lamp having two electrodes;

a step down auto transformer driving said lamp;

a power supply means providing intermittent current to said step down transformer; and

means for providing a starting voltage gradient between one of said electrodes and said power supply and for establishing the magnitude of said starting voltage gradient independently of said step down auto transformer.

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