United States Patent [19]

Kubo

[11] **3,886,405**

[45] **May 27, 1975**

[54] **DEVICE FOR OPERATING DISCHARGE LAMPS**

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[73] Assignee: **Mamiya Koki Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **Feb. 1, 1973**

[21] Appl. No.: **328,654**

[30] **Foreign Application Priority Data**

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Feb. 7, 1972	Japan	47-13417
Mar. 1, 1972	Japan	47-20562

[52] **U.S. Cl.** **315/246**; 315/DIG. 5; 315/151; 315/224; 315/283

[51] **Int. Cl.** **H05b 41/16**

[58] **Field of Search** 315/DIG. 5, 149, 151, 156, 315/224, 227, 240, 246, 283, 362

[56] **References Cited**

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Primary Examiner—R. V. Rolinec
Assistant Examiner—Lawrence J. Dahl
Attorney, Agent, or Firm—Wenderoth, Lind & Ponack

[57] **ABSTRACT**

The device disclosed herein fundamentally comprises current limiting means for limiting a current in a discharge lamp to below its rating until a predetermined point is reached in a half cycle of the alternating current and control signal generating means for applying a control signal to the current limiting means at the predetermined current control changeover point to suspend or depress the function of the current limiting means, so that the supply voltage viewed from the discharge lamp is equivalently increased and accordingly the device itself can be made smaller in size and lighter in weight. The device further comprises means for changing the current control point according to variation in the characteristics of its circuit elements or the lapse of time from the starting time of the discharge lamp in order to stably operate a discharge lamp such as a mercury arc lamp which is variable in vapor pressure and equivalent impedance. In addition, the device further comprises time locking means for actuating the control signal generating means after a given time, or keeping the function of the control signal generating means in suspended state for the given time after closing of a line switch, thereby to stably operate a discharge lamp which requires starting pulse or has an irregular discharge in the starting period.

15 Claims, 36 Drawing Figures

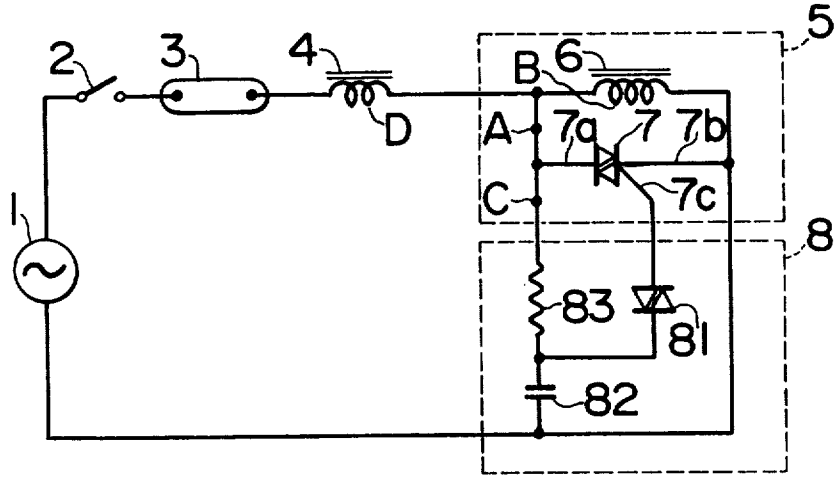


FIG. 1

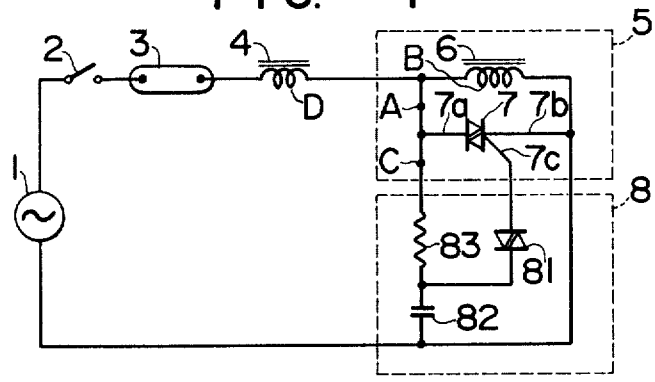


FIG. 2(a)

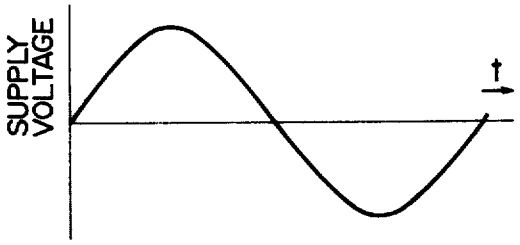


FIG. 2(b)

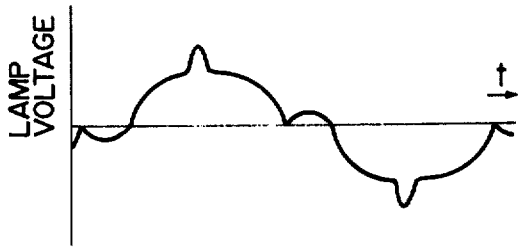


FIG. 2(c)

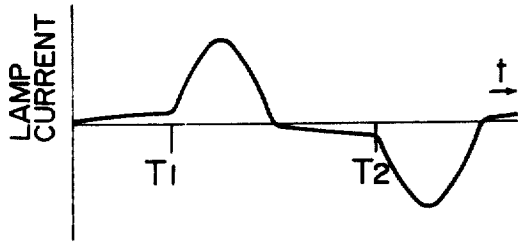


FIG. 3

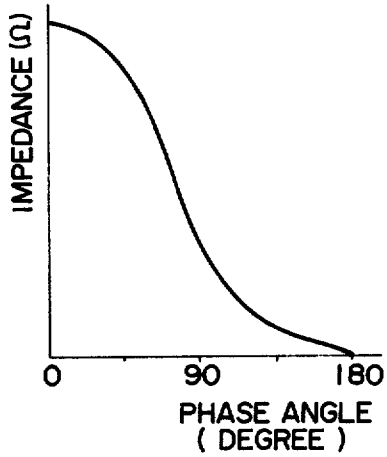


FIG. 4

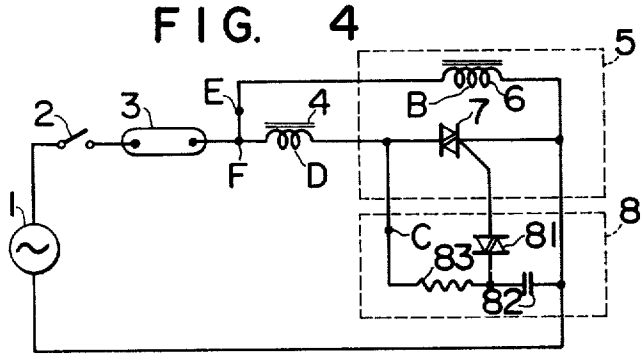


FIG. 5

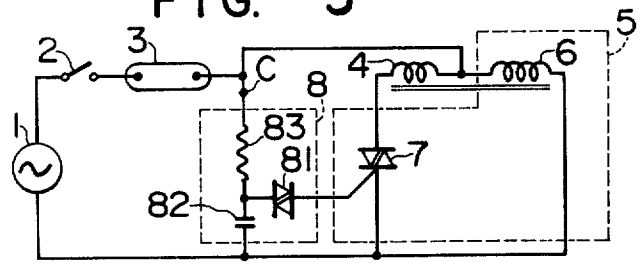


FIG. 6

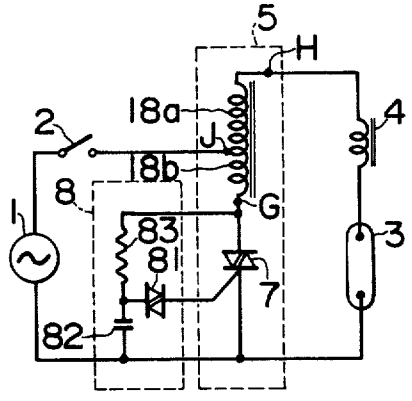


FIG. 7

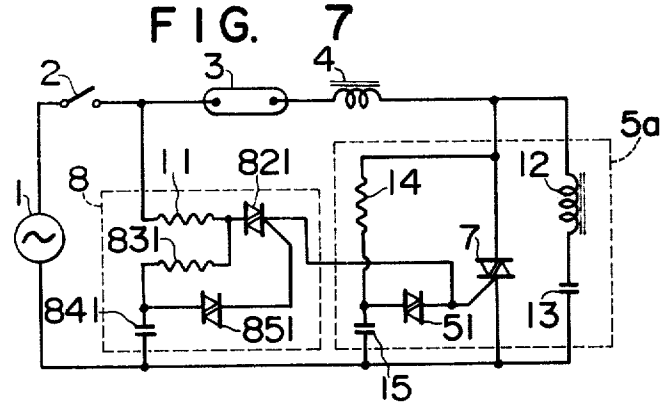


FIG. 8

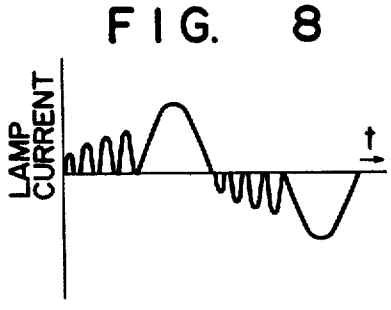


FIG. 9

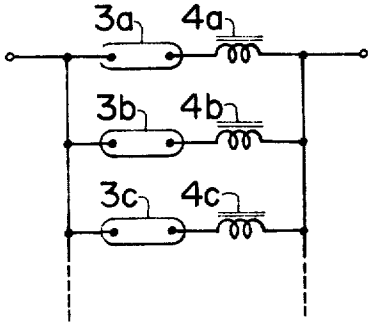


FIG. 10(a)

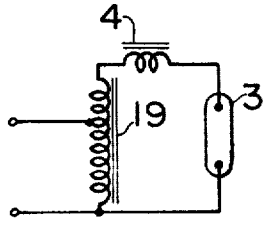


FIG. 10(b)

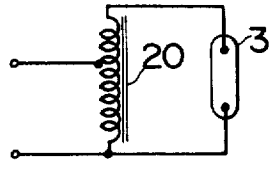


FIG. 11(a)

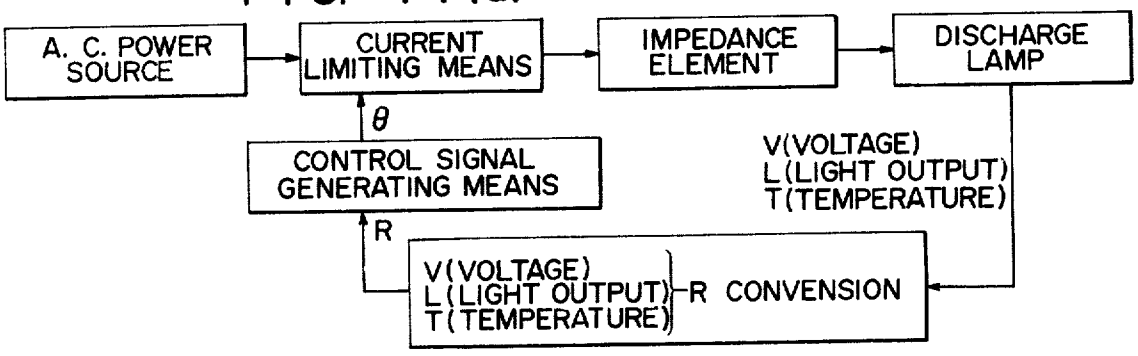


FIG. 11(b)

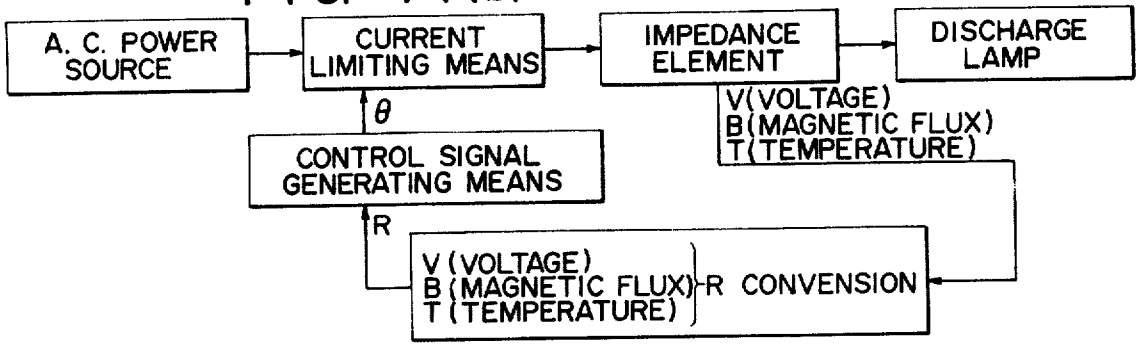


FIG. 11(c)

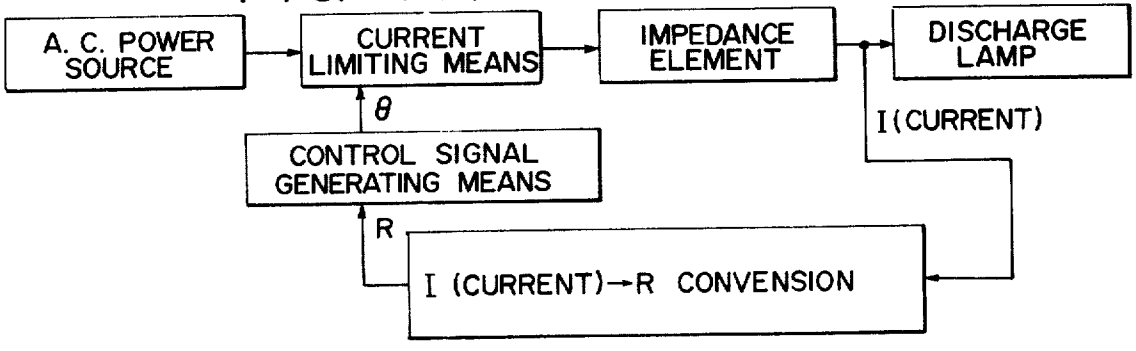


FIG. 11(d)

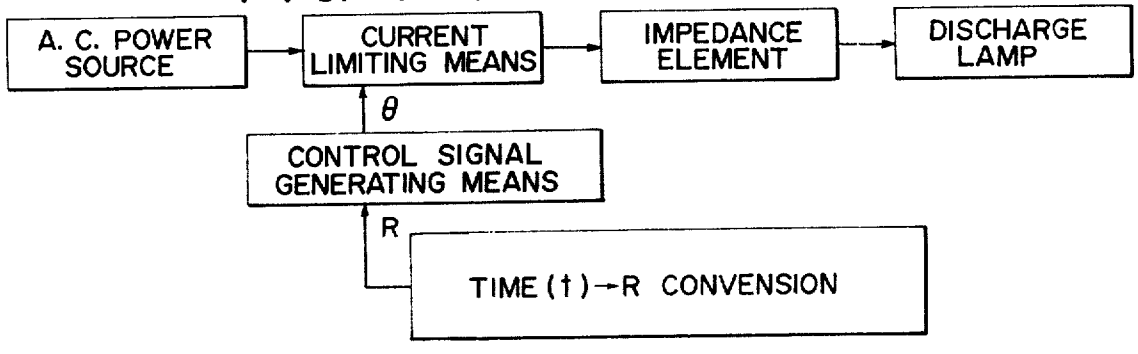


FIG. 12(a)

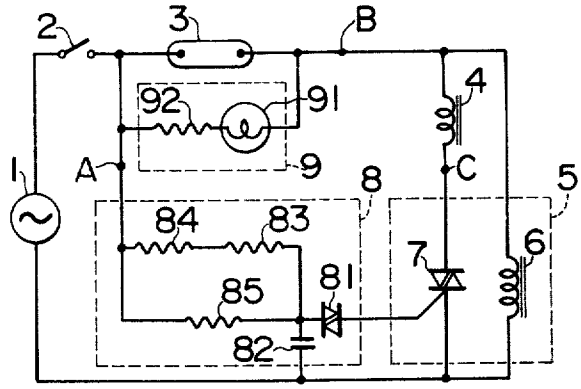


FIG. 12(b)

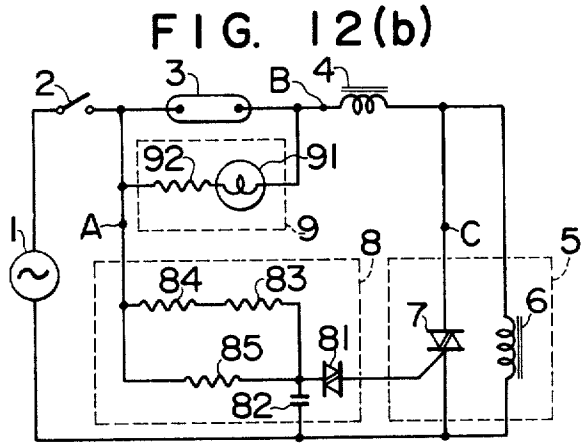


FIG. 12(c)

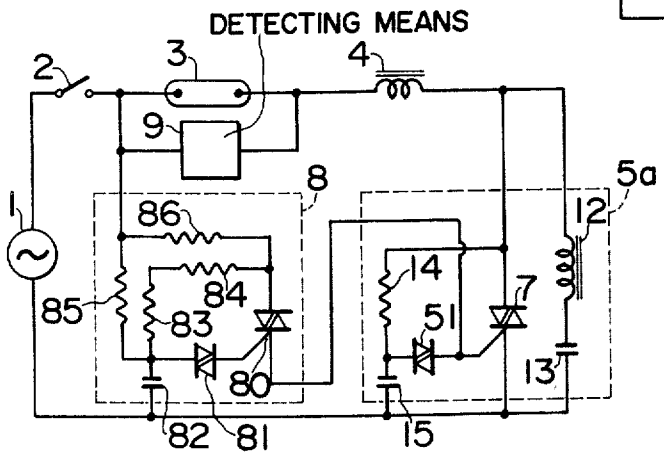


FIG. 12(d)

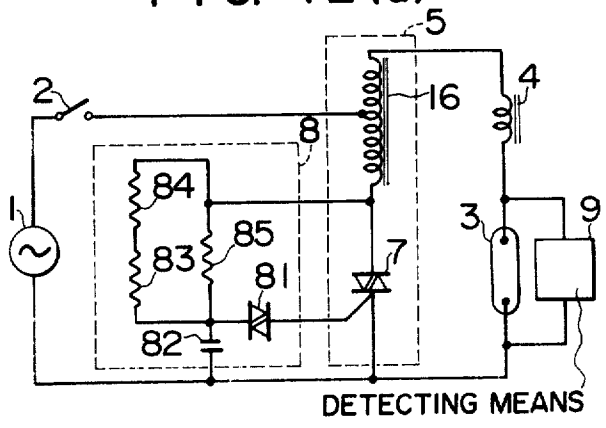


FIG. 13

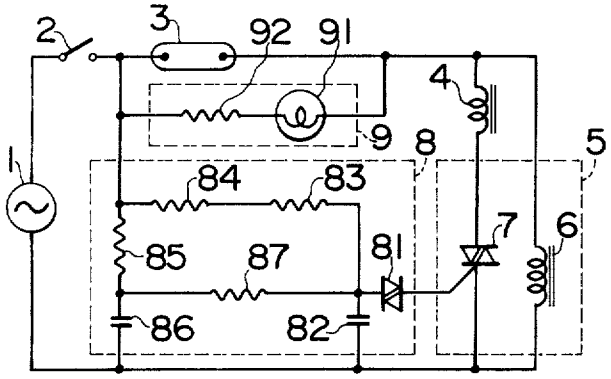


FIG. 14

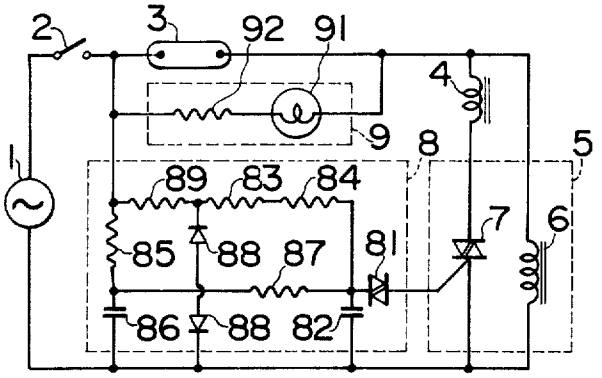


FIG. 15

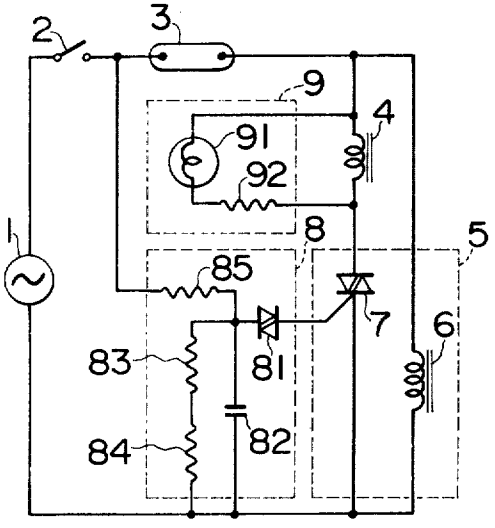


FIG. 16

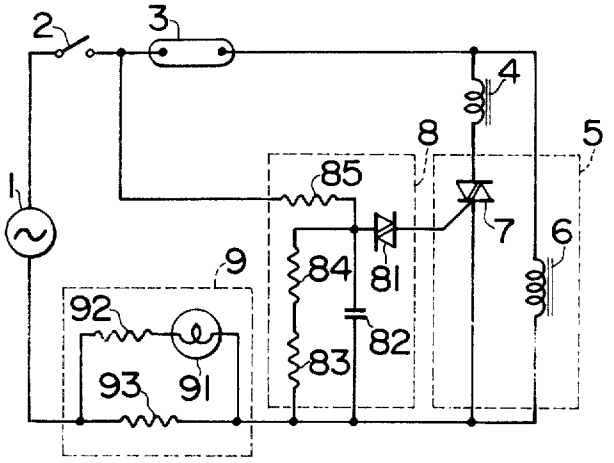


FIG. 17

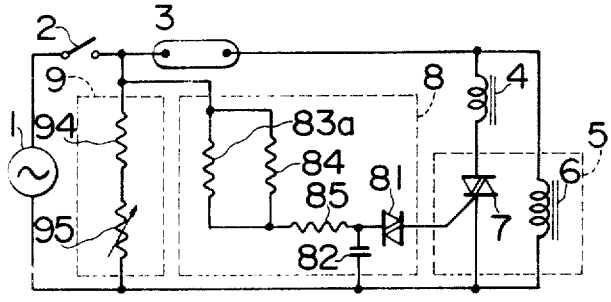


FIG. 18(a)

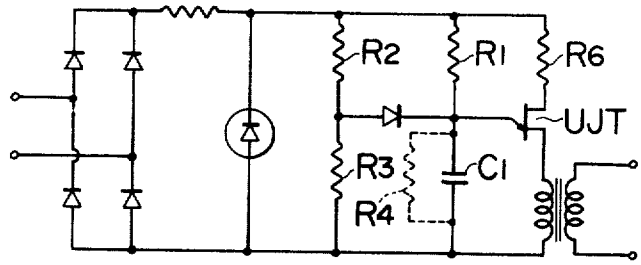


FIG. 18(b)

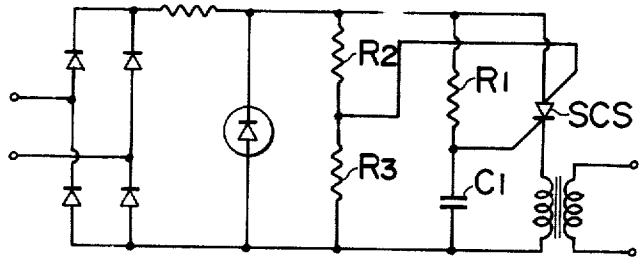


FIG. 18(c)

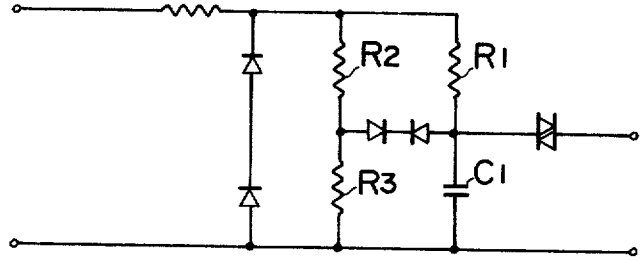


FIG. 19

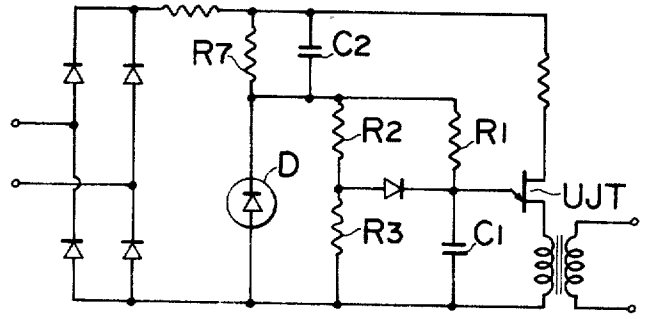


FIG. 20

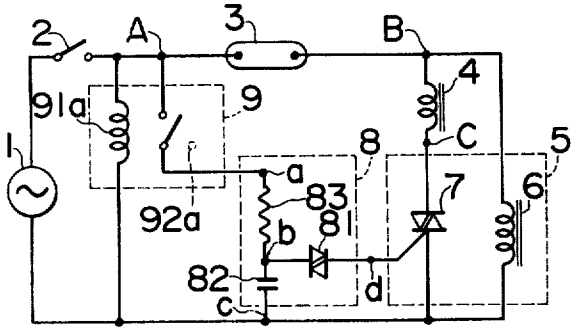


FIG. 21(a)

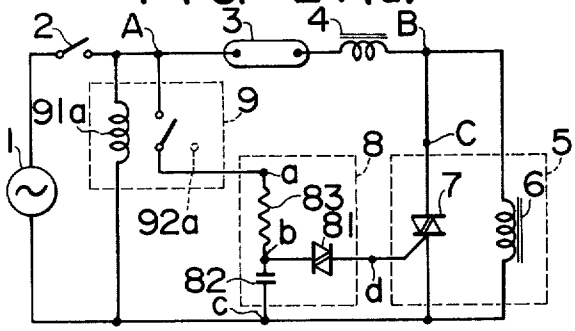


FIG. 22

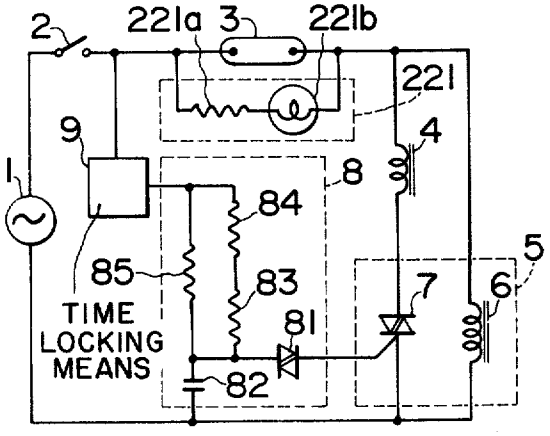


FIG. 21(b)

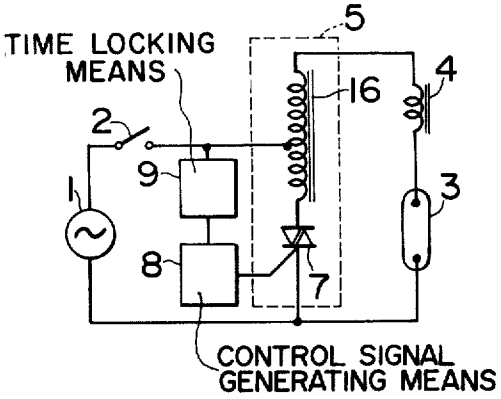


FIG. 21(c)

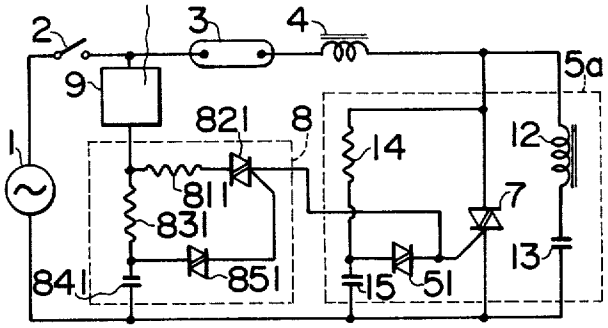
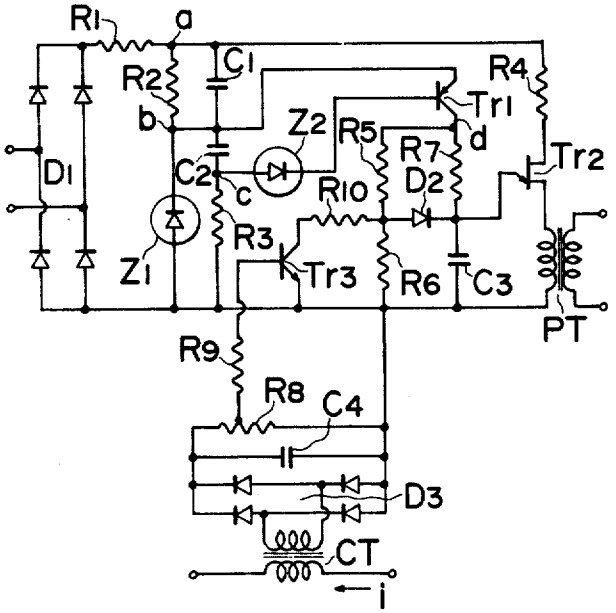


FIG. 23



DEVICE FOR OPERATING DISCHARGE LAMPS

BACKGROUND OF THE INVENTION

This invention relates to improvement of a device for operating a discharge lamp (hereinafter referred to as "a discharge lamp operating device" when applicable).

Heretofore, a large impedance element has been employed, as a ballast, for operating a discharge lamp. This impedence element is usually a coil wound on an iron core, and it is relatively heavy in weight, relatively large in size and high in cost.

For overcoming those problems created by the impedance element, a method of converting the voltage or current of an a.c. power source applied to the discharge lamp into a high frequency voltage or current thereby to equivalently increase the frequency of the power source, has been considered. However, this method involves problems such as a great power loss due to the iron core and a high cost in manufacturing a device for operating a discharge lamp.

Furthermore, the fundamental circuit for operating a discharge lamp is, in general, formed by a discharge lamp and an impedance element which are connected in series to an a.c. power source. In this circuit, it is necessary to decrease a supply voltage for the discharge lamp approximately to a lamp voltage, in order to operate the discharge lamp with a lower impedance value of the impedance element.

However, with such a supply voltage, the stability of the lamp operation for the variation of the supply voltage may be decreased, and it is therefore not suitable for practical use. Accordingly, usually a high impedance element and a high supply voltage are used.

These problems have been solved by the present invention with the result that the impedance element can be made smaller in size and lighter in weight, as will be seen in the detailed description of the specification.

For convenience of description, the method for solving the problem will be briefly described.

Although the conventional supply voltage is used in the present invention, the current flow in the discharge lamp is limited by current limiting means until a predetermined instant (which will be described in detail later) in a half cycle of the alternating current thereby making its output lower than its rated value and thereafter the function of the current limiting means is suspended or depressed thereby to increase its output, so that the rated output is obtained throughout each half cycle of the alternating current. As a result, the effective supply voltage viewed from the discharge lamp is lowered and the impedance element can be therefore made smaller in size.

Since the lamp current is limited to a low value by the current limiting means until a predetermined instant in each half cycle of the alternating current, this invention has the following advantages. This lamp current, thus limited to the low value, maintains a low current flow in the lamp, and therefore the peak voltage of the lamp is low, whereby dropout of the lamp can be prevented. Furthermore, since the current flowing in the lamp is thus slight, the ignition of the lamp can be readily accomplished at the predetermined time at which the function of the current limiting means is suspended or depressed. In addition, since the small current flowing until the predetermined time in each half cycle heats the cathode of the discharge lamp, the temperature of the lamp is maintained at a temperature suitable for the cathode oxide, and the service life of the cathode is therefore extended.

More specifically, for instance, in one example of the device for operating a discharge lamp in which a low impedance coil is employed as the impedance element while a high impedance element and a bi-directional controlled rectifier are employed as the current control means, electric current flows through the high impedance element connected in series with the circuit formed by the power source, the discharge lamp and the low impedance element until the current control point is reached in order to limit the current to a value lower than its rated value, and at the predetermined time the state of the bi-directional controlled rectifier becomes conductive thereby bypassing the high impedance element so that a large current flows the circuit.

However, when the discharge lamp such as a mercury discharge lamp which has an equivalent impedance changing for the starting period is operated by this method, another problem is encountered. In this case, the equivalent impedance of the lamp in the starting period is lower as the lamp has a low vapor pressure for the starting period. When the lamp operation is in a stationary state, the equivalent impedance is larger as it has a high vapor pressure.

If the current control point is chosen to occur when the discharge lamp produces its rated output during the starting period, an over-current will flow in the discharge lamp whereby the phenomena as to the equivalent impedance as described above is observed, which can damage the discharge lamp or the circuit elements.

Furthermore, if the discharge lamp requires starting pulses or has an irregular discharge in the starting period, the operation of the control signal generating means or the current limiting means is affected by the starting pulses or the irregular discharge. As a result, satisfactory operation and stability of the discharge lamp will not be achieved.

SUMMARY OF THE INVENTION

Accordingly, a first object of this invention is to provide a device for operating a discharge lamp which comprises means for equivalently lowering a voltage to be supplied to the discharge lamp and which is therefore small in size, light in weight, simple in handling, and high in reliability.

A second object of the invention is to provide an improved device for operating a discharge lamp which can stably operate a discharge lamp which has different characteristic between the starting time and the operating time, or which will require high pulsive voltage at the starting time, or which will have an irregular discharge.

A third object of the invention is to provide an improved device for operating a discharge lamp which functions to maintain the discharge lamp output constant despite variation in the characteristics of the discharge lamp, variations in the conditions of its circuit elements, and variations in its environmental conditions such as supply voltage.

A fourth object of the invention is to provide a device for operating a discharge lamp in which the discharge lamp is exchangeable with other discharge lamps and which has characteristics that are constant overtime.

The foregoing objects and other objects of the invention will become more apparent from the following detailed description and the appended claims when read

in conjunction with the accompanying drawings, in which like parts are designated by like numerals.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a circuit diagram illustrating one example of the device for operating a discharge lamp according to the invention;

FIGS. **2**(a)-**2**(c) showing the waveforms of a supply voltage, a lamp current and a lamp voltage in the circuit shown in FIG. **1**;

FIG. **3** is a graph showing the relationship between impedance of an impedance element and phase angle of a current control timing instant;

FIGS. **4, 5, 6** and **7** are circuit diagrams of other examples of the device for operating a discharge lamp according to the invention;

FIG. **8** is a diagram showing the waveform of a lamp current in the circuit shown in FIG. **7**;

FIG. **9** shows other combinations of discharge lamps and impedance elements;

FIGS. **10**(a) and **10**(b) show circuits which can be connected in place of the discharge lamp and impedance element in FIGS. **1** and **7**;

FIGS. **11**(a), **11**(b), **11**(c) and **11**(d) are block diagrams illustrating various detecting systems employed in the invention;

FIGS. **12**(a), **12**(b), **12**(c), **12**(d), **13** and **14** are circuit diagrams illustrating devices for operating discharge lamps which are based on a system of detecting the voltage, light output, or temperature of the discharge lamp;

FIG. **15** is a circuit diagram illustrating a device for operating a discharge lamp in which a system of detecting the voltage, magnetic flux, or temperature of an impedance element is employed;

FIG. **16** is a circuit diagram illustrating a device for operating a discharge lamp in which a system of detecting a current flowing in the discharge lamp is employed;

FIG. **17** is a circuit diagram illustrating a device for operating a discharge lamp in which a system of detecting the lapse of time is employed;

FIGS. **18**(a), **18**(b), **18**(c) and **19** illustrate other examples of the control signal generating means;

FIG. **20** is a circuit diagram illustrating a typical example of the device for operating a discharge lamp in which time locking means is provided for stably operating a discharge lamp which requires starting pulses or has an irregular discharge in the starting period;

FIGS. **21**(a), **21**(b) and **21**(c) are schematic diagrams illustrating time locking means employed in a device for operating a discharge lamp according to the invention;

FIG. **22** is a circuit diagram illustrating a device for operating a discharge lamp which is provided with time locking means and detecting means adapted to detect a voltage of the discharge lamp; and

FIG. **23** is a circuit diagram illustrating another example of the control signal generating means which has a time locking means formed by transistors, resistors and capacitors and serves to have a constant light output characteristic.

DETAILED DESCRIPTION OF THE INVENTION

Broadly speaking, the invention comprises three means: interrupting a voltage or a current, and transformer means for controlling an electric current flow in a discharge lamp.

With reference to FIG. **1**, there is shown one example of a device for operating a discharge lamp according to the invention in which the impedance means is employed. The circuit for this device comprises: an a.c. power source **1**; a line switch **2**; a discharge lamp **3**; a coil **4** employed as an impedance element having a relatively low impedance; current limiting means **5** constituted by a coil **6** employed as an impedance element having relatively high impedance and a bi-directional controlled rectifier **7**; and control signal generating means **8** constituted by bi-directional switching means **81**, a resistor **83** and a capacitor **82**. The current limiting means **5** operates to limit current flowing through the discharge lamp **3** and the coil **4**.

The operation of the circuit (FIG. **1**) is as follows. When the line switch **2** is closed the discharge lamp **3** is operated through the coil **4** and the coil **6** which are connected in series. This current can be limited because the coil **6** is a high impedance device.

However, as the capacitor **82** is gradually charged through the resistor **83**, the voltage of the capacitor **82** increases.

In this connection, the resistance of the resistor **83** has been predetermined so that the voltage of the capacitor reaches the switching voltage of the switching element **81** at a predetermined time when the alternating current is at a predetermined phase in each half cycle. Accordingly, at this instant, the capacitor is discharged through the switching element **81** and the control electrode **7***c* and second electrode **7***a* of the bi-directional controlled rectifier **7** thereby producing a control signal for the bi-directional rectifier **7**.

By means of this control signal, the first electrode **7***b* and the second electrode **7***a* of the rectifier **7** are substantially shorted, whereby the function of the current limiting is suspended. Accordingly, the current flowing in the discharge lamp **3** (hereinafter referred to as a lamp current when applicable) increases, that is, the output of the discharge lamp **3** increases. Thereafter, the lamp current decreases with the a.c. voltage, and when the lamp current through the bi-directional controlled rectifier **7** has reached about zero, the bi-directional rectifier **7** is turned off. The half cycle is thus completed.

The operation of the circuit in the next half cycle of the alternating current is the same as that described above except that the polarity is revered. Thus, the discharge lamp **3** is operated at its rated output throughout a complete cycle of the alternating current. Since the lamp current is limited to a low value by the current limiting means until a predetermined instant in each half cycle of the alternating current, this invention has the following advantages. This lamp current, thus limited to the low value, maintains a low current flow in the lamp, and therefore the peak voltage of the lamp is low, whereby dropout of the lamp can be prevented. Furthermore, since the current flowing in the lamp is thus slight, the ignition of the lamp can be readily accomplished at the predetermined time at which the function of the current limiting means is suspended or depressed. In addition, since the small current flowing until the predetermined time in each half cycle heats the cathode of the discharge lamp, the temperature of the lamp is maintained at a temperature suitable for the

cathode oxide, and the service life of the cathode is therefore extended.

In addition, if the predetermined, current control time described above occurs at an earlier instant during each half cycle of the alternating current without lowering the stabilization of the discharge lamp, the output of the discharge lamp will be increased more than the rated value thereof. In contrast, if the current control timing made to occur at a later instant, the output of the discharge lamp will be decreased. Thus the light output of the discharge lamp can be adjusted as required.

In addition, if the current control point is changed according to the variation of the voltage supply, the variation with time of the circuit elements, and the variation of environmental conditions, the output of the discharge lamp may be maintained constant, that is, it is possible to give a constant power characteristic to the discharge lamp.

The waveforms obtained by plotting the voltage supply, the voltage of the discharge lamp (hereinafter referred to as a lamp voltage when applicable) and the lamp current respectively against time (t) are shown in FIG. **2**, in which the current control time is represented by reference symbols T_1 and T_2.

In the circuit described above, since the inductance of the coil **4** is lower than that of a conventional ballast, the number of turns of the coil **4** is relatively small and the iron core of the coil **4** is also small. Therefore, the coil **4** is very small and is accordingly light in weight.

In addition, the inductance of the coil **6** is relatively high, but the current capacity thereof can be small. Therefore, although the number of turns of the coil **6** is great, a wire small in diameter and an a small iron core may be used for constructing the coil **6.** Accordingly, the coil **6** can be also made small in size and light in weight. It is apparent that the other components of the device are small. Especially, the resistor and the capacitor can be small in current capacity since they are to be used in the control circuit.

In FIG. **1**, the input terminal C of the resistor **83** may be connected to the power source side of the discharge lamp **3** or to the coil **4**, so that the above-described control signal generating means is not affected by the operating conditions of the discharge lamp **3.** Furthermore, it is possible to provide a load equivalent to the discharge lamp **3**, for instance, a transformer in place of the discharge lamp **3** in FIG. **1** in such a manner that the primary winding of the transformer is connected between the power source **1** and the coil **4** and the secondary winding thereof is connected to the discharge lamp **3.** Furthermore, each of the coils in FIG. **1** may be a complex circuit consisting of a coil and a capacitor. These modifications may be applied to other examples, described hereinafter, of the dvices for operating discharge lamps according to the invention.

In addition, in FIG. **1**, the input terminal A of the bi-directional controlled rectifier **7** may be connected to an intermediate point B of the coil **6.** In the circuit thus modified, even when the bi-directional controlled rectifier **7** becomes conductive, the effect of the coil **6** continues so that the coil **6** takes a part of the action of the coil **4.** Similarly, the input terminal A of the coil **6** may be connected to an intermediate point D of the coil **4,** so that the coil **4** takes a part of the action of the coil **6.**

In the above-described example, the current flowing through the discharge lamp is limited, by the high impedance element **6,** to a value smaller than the rated current until the predetermined time in each half cycle of the alternating current at which the current control point is reached, thereby maintaining a supply of ions in the discharge lamp. Accordingly, the current of the discharge lamp can be readily increased without application of a high voltage such as a pulse voltage, that is, without changing the supply voltage at the predetermined instant, thereby to stably operate the discharge lamp.

The predetermined current control point, that is, an instant (in a.c. phase angle) when the alternation of the impedance elements is caused by the control signal generating means in the circuit should be determined by taking into consideration the following description.

In the case where the current control point is advanced to zero in phase angle in a half cycle of the alternating current, no current limitation is caused. This is the same as in the conventional ballast, in order to stably operate the discharge lamp at its rated output, the impedance element must be high in impedance.

In contrast, if the current control point is delayed from the zero, an effective supply voltage viewed from the discharge lamp is reduced as was described before. Therefore, in order to obtain the rated output of the discharge lamp, the impedance element must have a low impedance. The relationship between the impedance of the impedance element and the phase angle is shown in FIG. **3.**

In general, the waveform of an alternating current in an approximately half cycle after the current control point has occurred is approximately equal to a sine waveform, and its equivalent frequency increases with the delay of the current control function. For instance, if the phase angle at the instant current control occurs is 90°, the equivalent frequency is approximately twice the frequency of the power source. The phase angle at the instant current control occurs, in general, between 50° and 100°, for the purpose of achieving the objects of this invention. Accordingly, if a coil is used as the impedance element as shown in FIG. **1**, the inductance of the coil is reduced by the effect of such an equivalent frequency as described above. In conclusion, with the delay of the current control point the coil can be made small in size, that is, the discharge lamp operating device can be made smaller in size and lighter in weight, but the power factor of the device becomes lower. Therefore, in determining the instant current control the effect of this power factor should be taken into consideration.

FIG. **4** is a second example of the device for operating a discharge lamp according to the invention, in which impedance is utilized as the current limiting means.

In the circuit shown in FIG. **4** the coil **6** is connected in parallel through the controlled rectifier **7** to the coil **4.** In this circuit, only the coil **6** operates until the occurrence of the current control operation in the A.C. cycle, and then the state of the controlled rectifier **7** becomes conductive, as a result of which coils **4** and **6** are electrically directly connected in parallel to each other. The current limiting function of the current limiting means **5** is reduced by this operation. More specifically, since the inductance of the coil **4** is much lower than

that of the coil **6**, most of the current of the discharge lamp **3** will flow through the coil **4**.

In this example, it should be noted that a part of the current of the discharge lamp **3** flows in the coil **6**. Therefore, the current capacity of the coil **4** may be smaller than that of the coil **4** of FIG. **1**, that is, the diameter of the wire of the coil **4** of FIG. **4** may be smaller than that of the coil **4** of FIG. **1**. Accordingly, the former coil **4** (FIG. **4**) is smaller than the latter coil **4** (FIG. **1**). The other operation of the circuit is the same as in the circuit of FIG. **1**. A transient voltage applied to the bi-directional controlled rectifier **7** is moderated by the coil **4**, as a result of which the bi-directional controlled rectifier is prevented from erroneously becoming cocnductive by the transient voltage. Accordingly, the discharge lamp operating device is improved in reliability, and the operation of the discharge lamp is also improved in stability.

In this example (FIG. **4**) also, the input terminal F of the coil **4** may be connected to the intermediate point B of the coil **6**, or the input terminal E of the coil **6** may be connected to the intermediate point D of the coil **4**.

The circuit described above was actually embodied with the following data:

Discharge lamp . . . a 400-watt mercury-arc lamp,
Supply voltage . . . 200 V,
Current control timing instant (in phase angle) . . . approximately 90°

Coil 4

Inductance . . . 10 mH
Current capacity . . . 4 A
Size . . . $7 \times 6 \times 4$ cm^3
Weight . . . 640 g

Coil **6**

Inductance . . . 800 mH
Current capacity . . . 0.4 A
Size . . . $7 \times 5.5 \times 4$ cm^3
Weight . . . 630 g

From a comparison of the above data with the following data of an impedance element, namely, a coil of the conventional ballast used with a similar discharge lamp, it is clear that the coil of the conventional ballast is about 4 times as large and about 3.5 times as heavy as the device of the invention. Therefore, it can be understood how small and light the device of the invention is.

Conventional Ballast

Inductance . . . 95 mH
Size . . . $15 \times 11 \times 9$ cm^3
Weight . . . 4,400 g

Furthermore, in conventional constant power type ballasts, for instance, a conventional ballast for 400 watts is approximately 11,500 g in weight. This weight can be reduced to about one-ninth thereof and the effect of a device with such a conventional ballast can be increased if the present invention is applied thereto, because according to the invention the constant power characteristic of the discharge lamp as was described above can be obtained and since the number of the component parts to be added thereto is small, the weight and volume of the device will hardly increase.

Another example of a device for operating a discharge lamp according to the invention, shown in FIG. **5**, is the same as the second example shown in FIG. **4** except that the coils **4** and **6** are wound on the same iron core.

In this example (FIG. **5**), since these coils **4** and **6** are wound on the same iron core, the directions of the currents flowing in the coils **4** and **6** are opposite to each other, and therefore the iron core will be little saturated. Accordingly, the sectional area of the iron core may be smaller than otherwise required. Consequently, the coil assembly **4** and **6** and accordingly the device can be made smaller in size and lighter in weight than those shown in FIG. **4**.

With reference now to FIG. **6**, there is shown a fourth example of a device for operating a discharge lamp according to the invention; reducing the supply voltage for the discharge lamp, thereby limiting a current flow in the discharge lamp.

In this example, the voltage applied to the discharge lamp **3** is lowered to below the rated value of the lamp by means of a transformer and a bi-directional controlled rectifier **7** until the current control point, previously described, in a half period of the alternating current, and thereafter the bi-directional controlled rectifier **7** becomes conductive to operate the discharge lamp at its rated output.

This example (FIG. **6**) can be effectively applied especially to the case where, for instance, a 200-V rating discharge lamp with a step-up transformer is used with a 100-V conventional power source.

The circuit shown in FIG. **6** comprises the control signal generating means **8**, the line switch **2**, the bi-directional controlled rectifier **7**, the discharge lamp **3**, the impedance element **4** and the a.c. power source **1** all of which were described previously, and further comprises windings **18***a* and **18***b* of transformer **18**.

The operation of the circuit shown in FIG. **6** is as follows. In each half cycle of the alternating current appearing at the upper terminal of the power source **1**, the a.c. voltage is divided by the primary winding **18***b* and the bi-directional controlled rectifier **7**. Since the impedance of the bi-directional controlled rectifier **7** is much higher than that of the primary winding **18***b*, most of the a.c. voltage is applied to the bi-directional controlled rectifier **7**. Therefore, the secondary winding **18***a* of the transformer is operated as a series impedance of the discharge lamp. Accordingly, the current **3** flows through the secondary winding **18***a* of the transformer and the impedance element **4**, thus operating the discharge lamp **3**.

In this case, the voltage applied to the discharge lamp **3** is below its rated voltage. Therefore, the current flowing in the discharge lamp **3** is limited by this low voltage supply and by the series conduit of the secondary winding **18***a* and the impedance element **4**. At the current control point in the a.c. cycle, the bi-directional controlled rectifier **7** becomes conductive due to a control signal produced by the control signal generating means **8** as was described previously, as a result of which almost all of the supply voltage is now applied to the primary winding **18***b*, and at the same time, a voltage higher than the supply voltage is induced between the terminals G and H of the coil assembly **18***a* and **18***b* owing to electromagnetic induction. The step up voltage thus induced is applied to the discharge lamp **3**, thereby increasing the output of the discharge lamp. This condition will be maintained till the termination of the a.c. half cycle.

The operation of the device in the next a.c. half cycle is the same as in the case described above except that the polarity is reversed. Thus, the discharge lamp **3** is operated at its rated output throughout one cycle of the alternate current.

In this example, since the current flowing in the discharge lamp **3** is limited until the current control point of the a.c. cycle, the primary winding **18***b* can be small on the basis of the equivalent frequency described before, and the device can be therefore made small in size and light in weight.

Depending upon the kinds of discharge lamps used, it is possible to connect the impedance element in parallel to the bi-directional rectifier **7** so that the voltage applied to the winding **18***b* can be increased to a certain degree even before the current control point occurs. In this case, since a voltage obtained by electromagnetic induction is added to the voltage supply, it follows that the voltage applied to the discharge lamp will increase.

Furthermore, if the magnetic coupling of the windings **18***a* and **18***b* is loosened to form a leakage transformer, the winding **18***a* can serve as the impedance element **4.**

FIG. **7** shows a further example of a device for operating a discharge lamp according to the invention by employing the method of interrupting a voltage or a current.

The operation of this device is as follows. In each half cycle of the alternating current, when the line switch **2** is closed, a capacitor **15** is charged through a discharge lamp **3,** a coil **4,** and a resistor **14.** When the voltage of the capacitor **15** reaches the switching voltage of a bi-directional switching element **51,** the capacitor **15** is discharged through the switching element **51,** thus producing a discharge current. This discharge current flows to the control electrode of a bi-directional control rectifier **7** thereby making the latter conductive.

At the same time, the the capacitor **13** which has been charged through the discharge lamp **3** and the coils **4** and **12,** is discharged through the bi-directional controlled rectifier **7** and coil **2** thereby to oppositely charge the capacitor **13.** Then the electric charge in the capacitor **13** is transferred in a reverse direction through the bi-directional controlled rectifier **7** again owing to a commutating circuit consisting of the coil **12** and the capacitor **13.** In this case, the direction of the current flowing through the bi-directional controlled rectifier **7** and caused by the transfer of the electric charge is opposite to the direction of the discharge lamp current through the bi-directional controlled rectifier **7.** Therefore, when the current through the bi-directional controlled rectifier **7** has become approximately zero, bi-directional controlled rectifier **7** is turned off. That is, the bi-directional controlled rectifier **7** resumes its nonconductive state. Then, the voltage of the capacitor **15** again rises.

Thus, the conductive state and nonconductive state of the controlled rectifier **7** are repeated, as a result of which the current flowing in the discharge lamp is interrupted as shown in the first half of each half cycle of the alternate current in FIG. **8.**

At the current control point in the a.c. cycle described above, the control signal generating means **8** operates in the same manner as described above, thereby to feed a control signal through a resistor **11** and a small bi-directional controlled rectifier **821** having small capacity to the control electrode of the bi-directional controlled rectifier **7,** as a result of which the bi-directional controlled rectifier **7** becomes conductive. This conductive state of the circuit is maintained until the current of the bi-directional controlled rectifier **7** becomes approximately zero. Therefore, during this period, the function of the current limiting means **5***a* is suspended, that is, the current limiting means **5***a* operate as conductive means only.

Since the a.c. voltage or current is thus interrupted, forming a high frequency until the current control point therein is reached, even if the current flowing through the discharge lamp becomes an over-current because of the small inductance of the coil **4,** it will be prevented because the bi-directional controlled rectifier **7** becomes immediately nonconductive. Then, at the current control point is reached, this current limitation is suspended to increase the output of the discharge lamp. Thus, the discharge lamp can be operated at its rated output for a full cycle of the alternating current.

This control signal generating means **8** (in FIG. **7**) is applicable to a device for operating a discharge lamp in which another type of a.c. interrupting circuit with a bi-directional controlled rectifier is employed.

In the example shown in FIG. **7,** if a series circuit consisting of a resistor and a capacitor is connected in parallel with the bi-directional controlled rectifier, the bi-directional controlled rectifier may be operated under suitable conditions. Furthermore, if a reactor is connected in series with the bi-directional controlled rectifier **7,** stable operation of the bi-directional controlled rectifier **7** may be achieved.

In all of the examples described above, a bi-directional switching element, controlled rectifiers connected in parallel with and in opposition to each other, a saturable reactor or the like can be used in place of the bi-directional controlled rectifier **7** or **821,** if these elements are equivalent in performance to the rectifier **7** or **821.**

In these examples described above, instead of one series circuit consisting of the discharge lamp **3** and the impedance element **4,** a parallel circuit consisting of a plurality of circuits in which discharge lamps **3***a*, **3***b*, **3***c*, etc. and impedance elements **4***a*, **4***b*, **4***c*, etc. are connected in series respectively, can be connected as shown in FIG. **9.**

In addition, in the circuits shown in FIGS. **1** and **7,** the series circuit of the discharge lamp **3** and the impedance element **4** can be replaced by a circuit comprising a transformer **19,** a discharge lamp **3** and an impedance element **4** as shown in FIG. **10**(a) or by a circuit comprising a leakage transformer **20** and a discharge lamp **3** as shown in FIG. **10**(b).

Furthermore, the discharge lamp **3** shown in FIG. **4** or **5** can be replaced by a circuit shown in FIGS. **9,** 10(a) or **10**(b).

As is apparent from the above descriptions, in operating the discharge lamp by alternating current according to the invention, the output of the discharge lamp is limited to less than its rated value by the current limiting means until the current control point of a half cycle of the alternating current, and therefore the function of the current limiting means is suspended or depressed to increase the output of the discharge lamp and the rated output thereof can be thus obtained for each cycle of the alternating current. Accordingly, the effect whereby the effective supply voltage (viewed

from the discharge lamp) is lowered to shorten the period of time during which the discharge lamp produces its output, is utilized so that the value of the impedance element can be reduced while the rated output is produced from the discharge lamp.

Unlike the case where the supply voltage is merely reduced, the supply voltage for operating the discharge lamp again is the same as that in the case where the conventional ballast is employed. Therefore, the device for operating a discharge lamp according to the invention is lighter in size, smaller in size, stable against the supply voltage variation, inexpensive and highly stable.

However, in this invention, if the predetermined current control timing instant in each of the half cycles is selected so that the rated current is obtained from the beginning of operation of the lamp, discharge lamps such as mercury are lamps whose impedance become low during the starting period will suffer from the following disadvantage. That is, in this case, the lamp current becomes several times as large as the rated current. As a result, the discharge lamp may be damaged, or the circuit elements may be burned, that is, the service life of the discharge lamp may be rendered short. This disadvantage is overcome by this invention.

Described below are several examples of the device for operating a discharge lamp in which the current control point is changed according to variations in the characteristics of a discharge lamp, variations in the physical quantities of circuit elements, or the lapse of time after closing of a line switch whereby any type of discharge lamp can be stably operated.

For providing, the device as described above, there are considered several systems such as illustrated in FIG. **11**(a), (b), (c) and (d). FIG. **11**(a) is a block diagram illustrating a first system in which variations of the voltage, light output and temperature of a discharge lamp are detected, and the variations thus detected are converted into electrical resistances which will be applied to control signal generating means. FIG. **11**(b) is a block diagram showing a second system in which variations of the voltage, magnetic flux, and temperature of an impedance element are detected. FIG. **11**(c) is a block diagram showing a third system in which a current flowing through a discharge lamp is detected. FIG. **11**(d) shows a fourth system in which the time after closing of a line switch is detected.

A circuit shown in FIG. **12**(a) is constructed in accordance with the first system (FIG. **11**(a)) and comprises an a.c. power source **1**, a line switch **2**, a discharge lamp **3**, an impedance element **4** having relatively low value and current limiting means **5** comprising a bi-directional controlled rectifier **7** and an impedance element **6** having a relatively high impedance.

The circuit further comprises control signal generating means **8** which includes a bi-directional switching element **81**, a capacitor **82**, photosensitive means **83** such as a photosensitive resistance, photo cell, or a photo diode, and resistors **84** and **85**, and detecting means **9** which has a resistor **92** and light emitting means **91** such as an incandescent lamp, a glow lamp, an electroluminescent lamp, or a photo emitting diode.

The operation of this circuit is as follows: when the line switch **2** is closed, a current flowing in the discharge lamp **3** is limited by the impedance element **6**, that is, this current is smaller than its rated value. On the other hand, the capacitor **82** in the control signal generating means **8** is gradually charged through the resistor **85**, thus increasing its voltage.

In the starting period, the equivalent impedance of the discharge lamp **3** is low and the voltage across the discharge lamp is also low. Therefore, the light output of the light emitting means **91** in the time locking means **9** is small, and the resistance of the photosensitive means **83** is therefore very high. Consequently, this circuit **83** is negligible for the charging of the capacitor **82**.

When the voltage of the capacitor **82** reaches the switching voltage of the switching element **81**, it will quickly become conductive. Therefore, the capacitor **82** is discharged through the element **81** thereby forming a trigger control signal for the bi-directional controlled rectifier **7**. As a result, the bi-directional rectifier **7** is substantially shorted, that is, the impedance element **6** is shorted thereby to suspend the function of the current limiting means **5**. Therefore, only the low impedance element **4** is left as an impedance element in the circuit, as a result of which the current flowing in the discharge lamp **3** is increased to operate the discharge lamp **3**.

In this connection, the current control point instant in a half of the alternate current, at which the current limiting function of the impedance element **6** is suspended, is determined by the resistance of the photosensitive means **83** in the starting period. For instance, the current control point is determined so that the current flowing in the discharge lamp in the starting period is of the order of 150 to 200 percent of the rated current.

Then, when the current flowing through the bi-directional controlled rectifier **7** becomes about zero, the bi-directional controlled rectifier **7** is changed to its nonconductive state, and the circuit is restored to its initial conditions.

The operation of the circuit in the next half cycle is the same as in the case described above except that the polarity is reversed.

Soon, the vapor pressure, equivalent impedance, and voltage of the discharge lamp increase. At this time, if the current control point were kept unchanged, the lamp current would decrease. However, upon an increase of the voltage of the discharge lamp, the light output of the light emitting means **91** in the detecting means **9** increases, and therefore the resistance of the photosensitive resistance element decreases. As a result, the voltage of the capacitor **82** increases more quickly. Therefore, the instant at which the bi-directional controlled rectifier **7** is changed to its conductive state occurs earlier, that is, the current control point of the a.c. cycle when the current limiting function caused by the impedance element **6** is suspended, occurs earlier, thereby preventing the decrease, described above, of the lamp current. Thereafter, the lamp current is gradually and stably reduced to the rated value.

As the light output of the discharge lamp **3** reaches its rated value, the resistance of the photosensitive means **83** becomes very low. However, if each concerned constant is determined so that the current control timing point is such that the rated output is obtained by the resistor **84** connected in series with the photosensitive means **83**, the lamp current will stably become its rated value, that is, the discharge lamp **3** will be operated at its rated conditions.

Thus, according to the invention, in the device for operating a discharge lamp in which a current flow in the discharge lamp is limited until a current control timing point is reached and the low impedance element is employed as a stabilizing impedance element to make the device smaller in size and lighter in weight, even if the discharge lamp is such that the equivalent impedance and lamp voltage thereof in the starting period is different from those at the time when the rated light output is emitted from the discharge lamp, it can be stably operated by changing the current control timing point through detection of the conditions of the lamp in the starting period.

In the circuit shown in FIG. 12(a), a terminal A, on the power source side, of the control signal generating means 8 may be connected to a point B where the discharge lamp 3 and the light emitting means 91 are connected together, or to a point C between the small impedance element 4 and the bi-directional controlled rectifier 7. In these cases, the supply voltage for the control signal generating means 8 corresponds to the variation in the characteristics of the discharge lamp, and therefore the starting operation of the discharge lamp 3 can be made stabler.

This can be applied to other examples which will be briefly described with reference to FIGS. 12(b), 12(c) and 12(d). In these examples, means for improving the starting characteristic of the discharge lamp are the same as those in FIG. 12(a).

A device for operating a discharge lamp shown in FIG. 12(b) is also based on the system of switching the impedance elements. The impedance elements 4 and 6 are in series with the discharge lamp 3 until the current control point is reached, that is, the current is limited by the high impedance element 6, and at the time the current control point is reached the bi-directional controlled rectifier 7 is changed to its conductive state to increase the current flow in the discharge lamp.

A circuit shown in FIG. 12(c) employs a system for interrupting a current flowing in a discharge lamp. In this circuit, a current interrupting circuit 5*a* consisting of a bi-directional controlled rectifier 7, capacitors 15 and 13, a resistor 14, a bi-directional switching element 51, and a coil 12 operates to interrupt the current flowing in the discharge lamp 3 so as to change it into a high frequency current thereby to limit the current until the time a current control point is reached in the half period of alternate current. At the current control point the controlled rectifier 7 is changed to its state, and this condition of the bi-directional rectifier 7 is maintained until the end of the half cycle.

A circuit shown in FIG. 12(d) employs the system for reducing a supply voltage. In this circuit, as the bi-directional controlled rectifier 7 is maintained non-conductive until the current control point, if the voltage supply is lower than the rated voltage of a discharge lamp 3, no primary current will flow in a transformer 16, that is, the voltage supply will not be increased. Accordingly, a low voltage is applied to an impedance element 4 and the discharge lamp 3, thus limiting the current flow in the discharge lamp 3.

At the time the current control point is reached, the bi-directional controlled rectifier 7 is changed to its conductive state, as a result of which the primary current flows in the transformer 16, the supply voltage increases, and the current flow in the discharge lamp 3 increases.

In the circuits described above, the discharge lamp may be replaced by an equivalent load such as the primary side of a transformer with its secondary side being connected to the discharge lamp.

The circuit shown in FIG. 12(a) can be modified as illustrated in FIG. 13. In this modified circuit, the phase of a voltage across a capacitor 86 lags behind that of a voltage supply owing to the capacitor 86 and resistor 85, while a capacitor 82 is charged through a resistor 87. Therefore, the operation of a bi-directional switching element 81 is stable even in the case where the current control timing instant is delayed (in phase) in the starting period.

FIG. 14 illustrates a modification of the circuit shown in FIG. 13. In this modification, instability in the starting operation of the discharge lamp, which may be caused by the variation of a voltage supply, is suppressed by means of Zenor diodes 88 which are connected in series and back-to-back.

FIG. 15 illustrates one example of a device for operating a discharge lamp in which a voltage across an impedance element is detected according to the invention. In this example, in the starting period, a lamp current is large, and the light output of a light emitting means is therefore great, that is, the resistance of photosensitive means 83 is low. Therefore, the resistance of a circuit formed by the photosensitive means 83 and a resistor 84 can be determined substantially by the resistance of the resistor 84. Accordingly, a part of the current flowing through a resistor 85 to a capacitor 82 will flow to the circuit consisting of the photosensitive means 83 and the resistor 84.

As a result, the instance at which the voltage of the capacitor 82 reaches the switching voltage of a bi-directional switching element 81 will be delayed, that is, the switching instant of the switching element 81 or the current control point described above will be delayed (in phase) by a half cycle of the alternating current.

As the voltage of the discharge lamp 3 increases, the voltage of the impedance element 4 decreases. Accordingly, the resistance of the photosensitive means 83 increases, that is, the part of the current described above decreases. Therefore, the voltage of the capacitor 82 will reach the switching voltage of the switching element 81 earlier.

Soon, the light output of the discharge lamp 3 reaches its rated value, and the discharge lamp 3 is operated at its rated output at the current control point. This example is provided according to the system described with reference to FIG. 11(b).

Shown in FIG. 16 is a circuit provided in accordance with the system describe with reference to FIG. 11(c). In this circuit, a current flowing through a discharge lamp 3 is converted into a voltage across a resistor 93. The operation of this circuit is the same as that of the circuit of FIG. 15.

FIG. 17 shows one example of a device for operating a discharge lamp in which the current control point is changed as a function of the time passing after the starting time of the discharge lamp. This example is provided on the basis of the system described with reference to FIG. 11(d). However, it has an additional effect, which will become more apparent later, in that the starting of the function of control signal generating means is delayed.

The circuit comprises a resistor **94** for heating a thermistor **83a** whose resistance is very high at room temperature, and a variable resistor **95** which is used to control a current flowing through the resistor **94** thereby to adjust a temperature rise thereof.

In this circuit, when a line switch **2** is closed, the discharge lamp **3** starts to discharge, and at the same time, a current flows in the heater **94** thereby to heat the latter. Since the resistance of the thermistor **83a** is very high at room temperature, a current for charging the capacitor **82** flows through resistors **84** and **85.** Therefore, the current control timing instant will occur at a relatively late point in a half cycle of the alternate current.

With the lapse of time, the temperature of the thermistor **83***a* is raised by the heating operation of the resistor **94,** that is, the resistance of the thermistor is decreased. Therefore, the charging speed of the capacitor **82** gradually increases. Therefore, the current control point is advanced in each half cycle of the alternating current, and soon the discharge lamp **3** will be operated at its rated output. At this time, the resistance of the thermistor **83***a* is low and the charging speed of the capacitor **82** is therefore determined substantially by the resistance of the resistor **85.** Therefore, the values of the capacitor **82** and the resistor **85** should be determined so that the current control point lies in the range such that the discharge lamp is operated at its rated output.

In this connection, it is possible to use other elements whose characteristics are changed with time, in place of the indirectly heated thermistor described above.

FIGS. **18**(a), **18**(b) and **18**(c) show other examples of the control signal generating means.

In the examples illustrated in FIGS. **12**(a) through **17,** the resistance **83** or **83***a* is changed with the variations of the voltage, current, output and temperature of the discharge lamp, and with the variations of the voltage, magnetic flux and temperature of the impedance element, until the discharge lamp is operated at its rated output from the starting time.

If described with reference to FIG. **18**(a), these variations are considered the same as those obtained by varying the resistance of a resistor **R1** or the resistance of a resistor **R4** connected parallel to a capacitor **C1.** In the circuit of FIG. **18**(a), even if the resistance **R1** or **R4** is linearly varied, the variation of the time at which the control signal is generated from the control signal generating means is not linear, that is, this time is not varied until a certain value of the resistance is reached, and thereafter is abruptly varied. Therefore, the unstable operating conditions of the device are sometimes observed till the rated light output of the discharge lamp is obtained.

In the examples shown in FIGS. **18**(a), **18**(b) and **18**(c), the resistance of the resistor **R1** or **R4** is fixed, while the resistance of a resistor **R2** or **R3** is varied by sensing variations in the characteristic of the discharge lamp or circuit so as to substantially linearly change the current control point described above. This is a so-called pedestal control, and the current control point can be stably changed in a wide range.

FIG. **18**(a) illustrates an example in which alternating current subjected to full-wave rectification is applied to a uni-junction transistor (UJT), FIG. **18**(b) illustrates an example which employs a silicon controlled switch (SCS), and FIG. **18**(c) illustrates an example in which alternating current is applied to a bi-directional switching element.

Shown in FIG. **19** is a further example of the control signal generating means which controls the output of the discharge lamp such that it is constant. In this example, a voltage proportional to the supply voltage is added through a resistor **R7** and a capacitor **C2** to the constant voltage obtained by a Zenor diode **D,** and the voltage obtained by this addition is used as the base voltage of a unijunction transistor **UJT.**

When the supply voltage increases, the peak voltage of the uni-junction transistor UJT increases also. As a result, the current control point occurs late thereby to suppress or prevent the increase of the lamp current. In contrast, when the supply voltage decreases, the peak point voltage of the unijunction transistor UJT decreases also. As a result, the current control point occurs early thereby to prevent the decrease of the lamp current.

Thus, it is possible to make the light output of the discharge lamp constant, regardless of the variation of the voltage supply, by properly determining the values of the resistor **R7** and the capacitor **C2.**

Thus, by the additional provision of means which operates to change the current control point in the a.c. waveform according to variation in the characteristics of the discharge lamp in its starting period, resulting variation of the physical quantities, such as current and voltage, of the circuit elements, or the lapse of time after the starting time, a device for operating a discharge lamp which can stably operate any discharge lamp, can be obtained.

Hereinafter, several examples of the device for operating a discharge lamp according to the invention, in which the discharge lamp requires starting pulses or has an irregular discharge will be described.

Shown in FIG. **20** is one example of a device for operating a discharge lamp according to the invention which comprises: an alternating current power source **1**; a line switch **2**; a discharge lamp **3**; an impedance element **4** having a relatively low impedance; current limiting means **5** constituted by an impedance element **6** having a relatively high impedance and a bi-directional controlled rectifier **7**; control signal generating means **8** comprising a bi-directional switching element **81,** a capacitor **82** and a resistor **83**; time locking means **9** having a coil **91***a* and its contact means **92***a*.

The operation of this circuit is as follows. Upon closing of the line switch **2,** the discharge lamp **3** is operated, but its current is limited by the high impedance element **6** to a value lower than its rated current.

In general, discharge lamps are liable to have irregular discharge characteristics in the starting period. For instance, some discharge lamps will have an irregular discharge for a period of several cycles of an alternating current applied thereto after being switched on, and some discharge lamps, for several tens of seconds. The cause for this irregular discharge cannot be simply determined, because various factors such as lamp current, ambient temperature and lapse of time, can be considered for the irregular discharge.

Therefore, if the time locking means **9** is set so as to close its contact **91** after the irregular discharge is over and the discharge lamp has been stably operated, upon termination of the irregular discharge a terminal *a* of the control signal generating means **8** is connected to a terminal **A** of the power source **1.**

During each half cycle of the alternating current, since the terminal *a* is thus connected to the power source **1**, the capacitor **82** of the control signal generating means **8** is gradually charged through the resistor **83**.

In this case, if the resistance of the resistor **83** is determined in advance so that the voltage of the capacitor **82** reaches the switching voltage of the bi-directional switching element **81** at a current control point during a half cycle of the alternating current, at the time the predetermined current control point is reached the bi-directional switching element **81** becomes conductive and the capacitor **82** is therefore discharged through the switching element **81** thereby to produce a control signal for the bi-directional controlled rectifier **7**.

The bi-directional controlled rectifier **7** becomes substantially conductive by the control signal thus produced, that is, the high impedance element **6** is short-circuited by a circuit formed by the bi-directional controlled rectifier **7** and the low impedance element **4**. In this case, since the only impedance element left active in the circuit is the low impedance element **4**, the current flowing in the discharge lamp **3** increases, that is, the output thereof increases.

Thereafter, the lamp current decreases with the voltage of the alternating current, and the half cycle of the alternating current waveform terminates.

During the next half cycle, the operation of the circuit is carried out in the same manner as described above except that the polarity is reversed.

Accordingly, the discharge lamp **3** can be operated at its rated output for a full cycle of the alternating current.

As is apparent from the above description, in order to prevent the incorrect operation of various means in the circuit which are found when a discharge lamp which requires pulses for starting discharge after switched being on is operated on when the operation of current limiting means such as a bi-directional controlled rectifier is made unstable by the irregular discharge of the discharge lamp, the control signal generating means is actuated by the time locking means after a given time thereby to suspend or depress the function of the current limiting means at the instant the current control point is reached during every half cycle of the a.c. input for a given time until the discharge lamp beings to operate in a stable manner. As a result, the operation of the discharge lamp can be carried out more stably.

In the circuit shown in FIG. **20**, the contact means **92**a of the time locking means **9** may be provided at a point *b* or *c* of the control signal generating means **8**, or may be inserted in series with the bi-directional controlled rectifier **7**.

In addition, if the contact means of the time locking means **9** is such that it will open by the operation of the time delay relay for the time locking means, the contact may be connected between the points *b* and *c* of the control signal generating means **8**.

Instead of the time delay relay for the time locking means an element such as a bimetal, transistor, bi-directional controlled rectifier or a circuit comprising resistors, capacitors and semiconductors which is equivalent in effect to the time delay relay, may be employed.

The contact means **92***a* of the time locking means **9** may be connected between the terminal *a* of the control signal generating means **8** and a point B where the discharge lamp **3** and the impedance element **4** are connected, or may be connected to a point C between the impedance element **4** and the bi-directional controlled rectifier **7**. In this case, the supply voltage for the control signal generating means **8** responds to variations in the characteristic of the discharge lamp. Therefore, it is possible to make the starting operation of the discharge lamp stabler.

These modifications applied to the circuit may be given to the following circuits (FIGS. **21**(a), **21**(b) and **21**(c)) which are provided according to the invention for the same purpose as that described above.

In these circuits, time locking means are the same as that shown in FIG. **20**.

The circuit shown in FIG. **21**(a) is a modification of the circuit illustrated in FIG. **20**.

An electric current flowing in a discharge lamp **3** is limited by a relatively high impedance element **6** which, together with a relatively low impedance element **4** and the discharge lamp **3** forms a series circuit until the current control point described above is reached in each half cycle of the alternating current. At instant the current control point is reached, a bi-directionl controlled rectifier **7** becomes conductive in the same manner as described above, and short-circuits the high impedance element **6**. As a result, the current flowing in the discharge lamp **3** increases.

The circuit shown in FIG. **21**(b) is designed for reducing a supply voltage for limitation of a current flow in a discharge lamps. In this circuit, a supply voltage is kept lower than the rated voltage of a discharge lamp **3** and therefore a bi-directional controlled rectifier **7** is also kept nonconductive until a current control point is reached. Accordingly, no primary current flows in a transformer **16**, that is, the transformer does not work as a booster in this case. Therefore, a voltage applied to the discharge lamp **3** and a relatively low impedance element **4**, is relatively low, thus limiting the current flow in the discharge lamp **3**. At the current control point, the bi-directional controlled rectifier **7** is caused to be conductive, and therefore the primary current flows in the transformer **16** and the voltage supply is increased. That is, the higher voltage is applied to the discharge lamp **3**, which increases the current flow in the discharge lamp **3**.

The circuit shown in FIG. **21**(c) employs the system of interrupting an electric current. An electric current flowing in a discharge lamp **3** is changed into a higher frequency current by means of a current interruption circuit **5***a* which comprises a bi-directional controlled circuit **7**, a coil **12**, capacitors **13** and **15**, a resistor **14**, and a bi-directional switching element **51**. This operation is continuously carried out until a control point is reached during each half cycle of the alternating current applied to the circuit. At the control point, a bi-directional controlled rectifier **821** relatively small in capacity is caused to be conductive. Since this conductive condition of the rectifier **821** is maintained until the half cycle of the alternating current is terminated, the bi-directional controlled rectifier **7** is kept conductive for the same period, thus suspending the operation of the current interruption circuit **5***a*.

The principles described with reference to FIGS. **20**, **21**(a), **21**(b) and **21**(c) can be applied to any of the circuits which will be described later.

These principles can be applied to the discharge lamp whose equivalent impedance in the starting period is roughly the same as that in the rated operating time period.

However, with the discharge lamp which has low vapor pressures and substantially shorted equivalent impedance in the starting period and takes several minutes till it becomes stabilized by increasing its vapor pressure to a certain value conditions, if the current control timing instant is fixedly set to occur at such an instant as the discharge lamp produces the rated output under the conditions that the circuit for the discharge lamp operates after a given time by means of the time delay means, there will be a danger of an over-current flowing in the discharge lamp with the result of damage of the latter.

This danger can be avoided as follows. The current control point is set at a late instant in the half cycle of the alternating current so that, after the starting switch has been closed and the discharge has become stabilized, the lamp current is, for instance, on the order of 150 to 200 percent of that obtained at the time the discharge lamp is turned on at its rated value. In addition, variation in the characteristics of the discharge lamp or resulting variations in the characteristics of circuit elements are converted into a variation such as electrical resistance which is applied to control a signal generating means so that the current control timing instant is automatically changed to occur at such an instant as to obtain the rated light output of the discharge lamp, thereby to stably light the discharge lamp.

For this purpose, the previously systems described with reference to FIGS. **11**(a) through **11**(d) can be applied to the device for operating a discharge lamp.

Devices for operating a discharge lamp in which the systems are employed will be described hereinafter.

A circuit shown in FIG. **22** comprises a detecting means **221** having a resistor **221a** and light emitting means **221b** used to detect the voltage of a discharge lamp **3**, control signal generating means **8** having photosensitive means **84** and a resistor **85**, and several elements such as the time locking means **9**, the line switch **2**, the impedance element **4** and the current limiting means **5** described with reference to FIG. **20**.

The operation of the circuit is as follows. When the line switch **2** is closed, the lamp current, being limited by the impedance element **6**, is smaller than the rated current of the discharge lamp. In this case, if the current control point described above is set so that a supply voltage is applied to the control signal generating means **8** through the time locking means **9** after the termination of the irregular discharge of the discharge lamp from the control point thus set the control signal generating means **8** starts its operation. In this time, the discharge lamp **3** has a low vapor pressure, equivalent impedance, and lamp voltage. Therefore, the light output of the light emitting means **221***b* in the detecting means **221** is small and the resistance of the photosensitive element **84** is very high.

Accordingly, in this case, the charge of the capacitor **82** is determined only by the resistance of the resistor **85**. On the basis of this fact, the current control point can be set by the resistor **85** so that the lamp current in the period of starting the operation of the discharge lamp is on the order of 150 to 200 percent of that obtained when the discharge lamp produces its rated output.

Soon, the vapor pressure of the discharge lamp **3** increases while the equivalent impedance thereof increases, as a result of which the lamp voltage also increases. In this case, at the current control point, the lamp current decreases, but the light output of the light emitting means **221***b* of the detecting means **221** increase with the lamp voltage, that is, the resistance of the photosensitive means **84** decreases with the increases of the light output, as a result of which the speed in charging the capacitor **82** will be changed faster. Consequently, the instant the bi-directional controlled rectifier **7** is changed to its conductive state, namely, the control point is reached earlier. Thus, the decrease of the lamp current can be avoided.

As the discharge lamp **3** produces its rated light output, the resistance of the photosensitive means **84** becomes low. In this case, if the constants of the elements concerned are determined so that the current control point is within a range such that the rated light output of the discharge lamp is obtained by means of the resistor **83**, which will allow the lamp current to stably have its rated value, the discharge lamp will be stably operated at its rated conditions.

FIG. **23** shows another example of the control signal generating means according to the invention, in which the time locking described above is obtained by a circuit comprising capacitors, resistors and transistors.

After application of the power source, the potential at a point *c* will gradually lower. When this potential becomes lower than a certain voltage determined by a Zenor diode **Z2**, a transistor Tr_1 will become conductive and the potential at a point *d* will soon become equal to that at a point *b*, which will allow the control signal generating means to generate a control signal.

In this system, a switching element having relatively small current capacity may be used in place of the Zenor diode **Z2** and the time locking can be readily obtained by changing the resistance of a resistor **R3**.

A circuit formed by resistor **R5**, **R6**, and **R7**, a diode **D2**, and a capacitor **C3** is stabler in control operation than a circuit formed only by the resistor R7 and the capacitor **C3**.

A circuit formed by a current transformer CT, diodes **D3**, a capacitor **C4**, a variable resistor **R8**, resistors **R9** and **R10**, and a transistor Tr_3 is used to detect the lamp current and to equivalently change the resistance of the resistor **R6** depending on a value obtained by the detection of the lamp current. For instance, the current control point can be set by adjusting the variable resistor **R8** so that the lamp current is of the order of 150 to 200 percent of the rated lamp current during the starting operation after the time delay.

Soon, the vapor pressure of the discharge lamp increases, the equivalent resistance of the discharge lamp increases, the lamp current decreases, and the base-emitter current of the transistor Tr_3 decreases. As a result, the equivalent resistance of the resistor **R6** increases, the current control point advances (in phase angle) thereby to prevent the decrease of the lamp current. Thus, the discharge lamp will soon produce its rated light output.

Thus, the occurrence of the control point can be adjusted mainly by the resistor **R6**. The increase of the resistance of the resistor **R6** will permit the discharge lamp to produce more light output than its rated value. A Zenor diode **Z1** can suppress the voltage variation in the transistor circuit.

Lagging in phase in a detection circuit of such a current feedback loop as described above can be readily compensated by capacitance and resistance thereby to obtain the stable operation of the discharge lamp.

Furthermore, in this example (FIG. 23), the peak voltage of the uni-junction transistor Tr_2 can be changed by a resistor R2 and a capacitor C1 for the variation of the voltage supply thereby to control the occurrence of the current control point, and this system provides a discharge lamp operating device having such a constant power characteristic as to have a constant light output during the period that the discharge lamp is operated at its rated light output.

The locking time caused by the time locking means provided in the discharge lamp operating device of the invention is roughly the same as that of the conventional discharge lamp operating device.

As is apparent from the above description, it is possible, according to the invention, to provide a discharge lamp operating device which is highly stable, highly reliable, smaller in size and lighter in weight and which operates properly for a discharge lamp requiring pulses or having the irregular discharge characteristics during the starting period, a discharge lamp having characteristics which vary with time, and a discharge lamp whose characteristics in the starting period differs from that in its rated operating period.

I claim:

1. A device for operating a discharge lamp comprising: an alternating current power source; a discharge lamp having a rated current value; a low impedance element, said low impedance element being a coil with a relatively few number of turns and relatively small in size; current limiting means comprised of high impedance means and bi-directional means coupled in parallel with said high impedance means for limiting electric current flowing in said discharge lamp to a value below the rated value thereof during a first portion in each half cycle of the alternating current of said power source, said current limiting means being inoperative during the remaining portion of each half cycle and being switched from operative to inoperative states by a control signal, said low impedance element and said current limiting means being connected between said alternating current power source and said discharge lamp; and control signal generating means connected to said current limiting means for applying a control signal to said current limiting means at a predetermined current control changeover point during each half cycle, said predetermined current control changeover point occurring at substantially **90°** with respect to current cross-over of each half cycle, whereby said current limiting means become inoperative after the control signal is applied to said current limiting means during each half cycle and the electric current flowing in said discharge lamp increases so that an effective current has said rated value for the half cycle.

2. A device as claimed in claim **1** which further comprises time locking means coupled to said control signal generating means for actuating said control signal generating means after a given time and suspending the function of said control signal generating means for the given time until said lamp has achieved stable operation after closing of a line switch.

3. A device as claimed in claim **1** in which said current limiting means comprises a high impedance element and a bi-directional controlled rectifier, said high impedance element being shunted by said bi-directional controlled rectifier at said current control point, and said control signal generating means comprises a bi-directional switching element, a resistor and a capacitor, said resistor and capacitor being coupled in series, said switching element coupled to the junction of said resistor and capacitor, said resistor and capacitor being selected so that a voltage of said capacitor reaches the switching voltage of said bi-directional switching element at the current control point, thereby applying a control signal to said bi-directional controlled rectifier.

4. A device as claimed in claim **1** in which said current limiting means comprises: a step-up transformer with a primary winding serving as a low impedance element and a secondary winding serving as a high impedance element, said secondary winding acting as a current limiting element in series with said low impedance element; and a bi-directional controlled rectifier rendered conductive by a control signal from said control signal generating means at said predetermined current control point to apply a supply voltage to said primary winding of said step-up transformer, whereby a voltage higher than the supply voltage is induced through electromagnetic induction of said step-up transformer to suspend the function of said current limiting element and thereby to increase said current flowing in said discharge lamp.

5. A device as claimed in claim **1** in which said current limiting means comprises a bi-directional controlled rectifier having a commutating circuit which is substantially composed of an inductor and a capacitor; and a bi-directional switching element for controlling the bi-directional controlled rectifier, to interrupt a current in said discharge lamp for the purpose of changing the current into a high frequency current until said current control point is reached, said control signal generating means providing a control signal which is applied to a control electrode of said bi-directional controlled rectifier to render the latter conductive for that portion of alternating current cycle between said predetermined current control point and the end of the respective half cycle.

6. A device as claimed in claim **1** which further comprises means for changing said current control timing point according to variation in the characteristics of said circuit and current limiting means and due to variation in the characteristic of said discharge lamp in the starting period thereof and operatively coupled thereto.

7. A device as claimed in claim **3** in which said low impedance element is connected in parallel to said high impedance element through said bi-directional controlled rectifier.

8. A device as claimed in claim **3** in which said high impedance element and said low impedance element are wound on one core.

9. A device as claimed in claim **6** in which said means for changing the current control point comprises: light emitting means for detecting variations in the characteristics of said circuit; and photosensitive means combined in said control signal generating means and controlling the latter according to light emitted by the light emitting means.

10. A device as claimed in claim **1** which further comprises means operatively coupled for changing said

current control point with the lapse of operating time after closing of a line switch.

11. A device as claimed in claim **10** in which said means for changing said current control point is an indirectly heated thermistor cooperating with said control signal generating means.

12. A device as claimed in claim **2** which further comprises means operatively connected for changing said current control point according to variation in the characteristics of said circuit after releasing the lock of said time locking means.

13. A device as claimed in claim **12** in which said means for changing said current control point comprises light emitting means, a resistor, and photosensitive means, said light emitting means detecting variation in the characteristic of said circuit, said resistor obtaining a suitable light output of the light emitting means said photosensitive means being combined in said control signal generating means and controlling the latter means according to the light emitted by the light emitting means.

14. A device as claimed in claim **12** which further comprises means operatively connected for changing said current control point with the lapse of operating time after releasing the lock of said time locking means.

15. A device as claimed in claim **14** in which said means for changing the current control point is an indirectly heater thermistor cooperating with said control signal generating means.

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