ABSTRACT: A continually pulsing electric system for operating a gas discharge lamp directly from an alternating current source is shown in which a gas discharge lamp is connected in series with solid state switching means directly across the terminals of an alternating current supply. Control means for the solid state switching means is included as is starting means for initially igniting the gas discharge lamp. Curves are included showing the increased efficiency under pulsed operation.
**Fig. 2.**

LIGHT OUTPUT VS. LAMP LOADING

- Continuous & Pulsed Operation of PMX 48 Lamp, 40mm pressure Xenon Fill.
- Pulsed Operation 250W Input
- Pulsed Operation 200V Input
- Continuous Operation

Lamp Voltage
Continuous Operation

% Gain Pulsed Operation over Continuous Operation

% Gain Pulsed Operation over Continuous Operation of Lamp.

**Fig. 3.**

% Gain of Pulsed Operation over Continuous Operation with varying phase angle operation.

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PULSED ELECTRIC SYSTEM FOR OPERATING A GAS DISCHARGE LAMP

The present invention relates to an electric system including an electric discharge lamp for operation directly connected across a source of alternating current in series with switching means, and to a method of operation thereof. Hereinafter, electric systems have been provided for producing a plurality of successive flashes of light in which the systems included energy storage devices, such as inductors and capacitors, connected in series or parallel with the gas discharge lamps. It was believed that these elements were necessary to store the electrical energy to provide a high instantaneous loading of the flash tube to achieve an efficient conversion of electrical energy to light energy in the form of a high intensity flash. The prior conventional alternating current flash producing systems included a step-up power transformer, a saturable reactor, a capacitor, a flashtube, and a triggering circuit supplying an initial ionizing pulse. These systems were disadvantageous because the saturable reactor, transformer, and capacitor were expensive, bulky and sometimes prone to failure especially under conditions of repetitive operation.

In a copending application Ser. No. 751,403 filed Aug. 9, 1968 by the applicant herein, there is shown an electric system including a discharge lamp directly connected across an alternating current line, the discharge lamp having an operating voltage higher than the line voltage so that the lamp is extinguished at the end of each half cycle and reignited during the next half cycle.

The present invention aims to provide improved efficiency over prior electric systems by providing an electric system for the operation of electric discharge lamps in which the capacitors and inductances of the prior art have been dispensed with and in which the lamp is energized at an efficient point in each cycle of alternating of the source.

In accordance with the invention this is accomplished by providing an electric system in which a flashtube or gas discharge lamp is operatively connected directly across the alternating current supply source in series with solid-state switching means. The flashtube is designed with an operating voltage equal to or less than the voltage of the source with which it is to be used. The solid-state switching means is controlled so as to energize the lamp at the desired time during each half cycle.

The system in accordance with the invention is advantageous in that it is suitable for operation as a substitute for the conventional system incorporating a step-up transformer, a saturable reactor and storage capacitor mentioned above.

The system in accordance with the invention is much less expensive than the step-up transformer-saturable reactor-storage capacitor system in that the step-up transformer, saturable reactor and capacitor are omitted, thus the cost of same is saved together with the space required thereby and the weight thereof.

In the saturable reactor-storage capacitor type system a 3000-watt lamp would have an operating voltage of 200–220 volts RMS. The operating current would be 18–20 amperes and the lamp would produce 24–26 lumens per watt, the lamp loading being about 123 watts per inch and the pressure 40 millimeters. Such a lamp requires a starting voltage of about 5000 volts. In an electric system in accordance with the invention a 3000-watt lamp would operate between 155 and 170 volts. The operating current would be 19–21 amperes and the lamp would produce about 24–26 lumens per watt. The watt loading for such a lamp would depend upon its length and gas pressure, and diameter of the tubing. A 40-millimeter pressure lamp operating with a watt loading of about 162 watts per inch, while a 70-millimeter pressure lamp would operate with a watt loading of about 182 watts per inch. Both the 40-millimeter and 70-millimeter lamps require a starting voltage of about 3000 volts.

In both systems starting means are required to initially ignite the discharge lamp, the starting means not being required after the lamp has become ignited. However in the case of the 70-millimeter lamp a keep-alive resistor connected across the switching means is required as will be explained hereinafter.

Generally speaking an efficient lamp operating and pulsed under either system of the above-described low pressure systems produces about 24–26 lumens per watt. Of course it is possible to obtain 30–50 lumens per watt using an electric system including high pressure high voltage lamps. However such systems and their components are considerably more expensive and weighty than the electric systems in accordance with the invention.

Other objects and advantages of the invention will be apparent from the following description and from the accompanying drawings which show, by way of example, embodiments of the invention.

The electric system in accordance with the invention in which the discharge lamp is operated in series with a solid state switching device directly from the power lines without the use of conventional energy storage devices such as capacitors or inductors has many uses including use in the graphic arts lighting field.

In the drawings:

FIG. 1 shows a schematic circuit of the system in accordance with the invention in which an electric system is shown including a starting circuit.

FIG. 2 shows a series of curves illustrating the improved operation of an electric system in accordance with the invention.

FIG. 3 is a curve showing the relationship between voltage angle of operation and luminous efficiency of pulsed operation in comparison to continuous operation.

Referring to the drawings there is shown in FIG. 1 a schematic circuit of an electric system in accordance with the invention. The system includes a pair of terminals 1 and 2 adapted to be connected to a source of alternating current which may vary or fluctuate between 190 and 250 volts. Across the terminals 1 and 2 is connected a bypass capacitor C1, its purpose being solely for passing starting pulses for the ignition of discharge lamp V1. The discharge lamp V1 is connected in series with the secondary of a starting transformer T1 and a solid state switching device S1 across the input terminals 1 and 2. The solid-state switching device S1 may be any suitable device such as bistable switches, triacs, a switching diode or a pair of controlled rectifiers, all of which are adapted to be controlled by means known in the art.

A suitable control means for operating the system in accordance with the invention includes a diac D1 connected to the gate of the Schottky type. Control means for the diac D1 includes a resistor R2 in series with a variable resistor R9 and a capacitor C5 connected across the switching diode. A resistor R5 is connected between the junction of the variable resistor R9 and the capacitor C5 to the diac D1, a filtering capacitor C6 being connected from the diac end of resistor R5 to terminal 2. The operation of this circuit is well known in the art and is described in General Electric, SCR Manual, 4th Edition, Chapter 9, pages 173 through 189 and in particular FIG. 9.15 on page 189, subchapter 9.4.2.

Triggering means for igniting the discharge lamp VI includes a primary for the transformer T1 connected in series with a capacitor C2 and a resistor R7 and a switch S1 across the terminals 1 and 2. Discharge means for the capacitor C2 through the secondary of the transformer T1 includes a solid-state switch S2 connected thereacross. The control means for the solid-state switch S2 is the same as for the control of the solid-state switch S1, but different resistance values are set out because of the lower capacity of the system. It will be noted that the variable resistors R8 and R9 are ganged for simultaneous operation which is necessary for proper operation.

As is usual the starting voltage for the discharge lamp V1 is higher than the voltage of the source thereby requiring the use of a starting circuit. However, the characteristics of the discharge lamp V1 are such that the lamp would operate con-
continuously in overloaded condition across the terminals 1 and 2 after being ignited. Such operation is not as advisable as a pulsed operation as will be seen by referring to the curves shown in FIG. 2, as the lamp would have shortened life or would be destroyed at higher input voltages. Curve 3 illustrates continuous operation of a discharge lamp V1 directly connected across the line terminals 1 and 2 and on which the voltage has been varied by means of a variac, the corresponding voltage being shown in curve 4. Curve 4 illustrates the characteristics obtained by pulsed operation of the discharge lamp V1 with a 100-volt input while curve 6 shows a corresponding operation with the input voltage maintained at 250 volts.

In FIG. 3 curve 7 illustrates the relationship between luminous efficiency of pulsed operation over continuous operation and the degree of phase angle operation for 200-volt input operation. Curve 8 of FIG. 2 illustrates the percentage gain of relative foot candles by pulsed operation with a 200-volt input as shown in curve 5 as compared with continuous operation as shown in curve 3. It will be noted that a considerable gain is achieved for pulsed operation over continuous operation, particularly for the lower lamp loading.

In order to obtain efficient operation component constants should be so selected with respect to the voltage of the system used as to keep the power loading constant under pulsed conditions. The resistors R9 and R8 are set to a corresponding input voltage to give correct loading of the lamp. The control circuit limits the integrated power to the lamp to its maximum operating voltage and provides high efficiency illumination. It will be noted that pulsed operation is 20–35 percent more efficient in lumens per watt than sine wave operation. Thus, if possible, the system components should be selected with respect to the terminal voltage so that operation is pulsed in the 10–110° range.

The impedance R1 shown connected across the switch SR1 is termed a keep-alive resistor and is preferably incorporated to maintain ionization in the lamps with comparatively higher pressure. For example, no impedance is required for a discharge lamp of 20–35 millimeter pressure. A 40-millimeter lamp preferably requires a 500-ohm resistor. A 70-millimeter lamp might preferably require a 200-ohm resistor. The resistors provide ionizing current for the discharge lamp during the period in which the solid state switch SR1 is not conducting.

In the operation of an electric system in accordance with the invention it is connected to a suitable source of alternating current. For example, in using an electric system of the constants set out herein, the electric source could operate from power sources varying in voltage from about 190 to 250 volts.

The gas discharge lamp V1 is ignited by closing the time delay switch S1 for 2–3 seconds which causes the triggering capacitor C2 to be charged through the primary winding of the transformer T1 and R7. Then, as determined by the constants of the starting circuit, the diac D2 is triggered causing the triac SR2 to be turned on. The capacitor C2 is then discharged through the primary of the transformer T1 producing one or more high frequency pulses across the discharge lamp V1 and through the bypass capacitor C1. Simultaneously, with the triggering of the triac SR2, the triac SR1 is also triggered, thereby completing the path for the high frequency pulses passed through the lamp V1, the bypass capacitor C1, and the secondary of the transformer T1. As stated above the variable resistors R8 and R9 are ganged so that the control circuits for the triacs SR1 and SR2 are triggered simultaneously. The lamp V1 will become ignited within a few seconds and the switch S1 is automatically opened at the end of its time delay period thereby deenergizing the starting circuit and rendering the biswitch SR3 inoperative.

The operation of the lamp is continued by the switching of the triac SR1 under the charge of the diac D1 and its control circuit. As shown the variable resistor R9 is manually adjusted to provide the desired wattage loading for the lamp V1 depending upon the voltage at the input. Of course, if desired, automatic control equipment may be associated with the adjustment of the variable resistor R9 so that the wattage output of the lamp V1 is maintained constant regardless of input voltage variations. During the operation of the lamp V1, the absence of ignition pulses through the secondary of the transformer T1, only a very small current passes through the bypass capacitor C1 under 60-cycle operation.

In the event the lamp V1 because of its pressure requires a keep-alive resistor R1 connected across the solid-state switching means SR1, a keep-alive resistor of appropriate resistance is used. This resistor maintains ionizing current through the lamp V1 when the switch SR1 is open, thereby causing the lamp to respond promptly to the larger flow of current passed upon the closing of the switch SR1.

In referring to the drawings it will be noted that a decided increase in efficiency is obtained by reason of the use of pulsed operation over continuous operation particularly for the lower wattage loading of the discharge lamp. It will be noted that a gain of 23 percent in efficiency is obtained at 3000-watt loading with an input voltage of 200 volts and an efficiency of 35 percent with input voltage of 250 volts as compared to the light output under continuous operation at the same wattage loading. However, if the wattage loading of the lamp V1 is dropped to 1800 watts a gain in light output using pulsed operation over the light output obtained with continuous operation is raised to about 50 percent. Advantage of this phenomena may be taken by arranging the constants of the electric system with respect to the voltage of the source with which the light is to be used that extremely efficient light output is obtained using comparatively low wattage.

An electric system found to operate in a satisfactory manner employs constants for the circuit components as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge lamp V1</td>
<td>General Electric P4A46 3000 watts, 181/4-inch arc length, 211/4 inches overall length, outside diameter 10 millimeters, inside diameter 8 millimeters, envelope quartz, filling pressure 40 millimeter xenon gas 2 mfd., 300 v. See — 80 turns, primary — 3, ferrite core, core area of one-half sq. inch</td>
</tr>
<tr>
<td>Capacitor C1</td>
<td>40.583</td>
</tr>
<tr>
<td>Transformer T1</td>
<td>RCA 2N5442</td>
</tr>
<tr>
<td>Solid-state switching device SR1</td>
<td>RCA 40593</td>
</tr>
<tr>
<td>Disc D1, D2</td>
<td>7.5 K.</td>
</tr>
<tr>
<td>Resistor R2, R3</td>
<td>56 K., coupled variable 0.005 mfd., 400 v.</td>
</tr>
<tr>
<td>Resistor R9</td>
<td>2.5 K.</td>
</tr>
<tr>
<td>Capacitor C5, C3</td>
<td>0.01 mfd., 200 volts</td>
</tr>
<tr>
<td>Transformer R5, R6</td>
<td>1 mfd., 300 volts</td>
</tr>
<tr>
<td>Capacitor C6, C4</td>
<td>150 ohms</td>
</tr>
<tr>
<td>Capacitor C2</td>
<td>time delay switch, 2–3 sec.</td>
</tr>
<tr>
<td>Resistor R7</td>
<td>S1 Solid-state switch SR2</td>
</tr>
<tr>
<td>Resistor R8</td>
<td>RCA 40576</td>
</tr>
<tr>
<td>56 K., coupled, variable</td>
<td></td>
</tr>
</tbody>
</table>

While the invention has been described and illustrated with reference to specific embodiments thereof it will be understood that other embodiments may be resorted to without departing from the invention. Therefore, the form of the invention set out above should be considered as illustrative and not as limiting the scope of the following claims.

I claim:

1. A continuously pulsing electric system for operating a gas discharge lamp directly from an alternating current source normally ranging from one lower voltage to a higher voltage, the electric system comprising a gas discharge lamp having full wattage loading under full wave operation at said lower voltage, solid-state switching means connected in series with said discharge lamp; circuit means connecting said series connected switching means and lamp substantially directly across said alternating current source, and utilizing solely the alternating current source impedance as ballast, for applying across said series connected switching means and discharge lamp substantially the full voltage and wave form of the source; adjustable control means for said solid-state switching
means operative responsive to the voltage of the source above the lower voltage for decreasing the phase angle of switching of said switching means so as to maintain the operating wattage of said lamp at a desired level, and triggering means for starting said lamp, said control means including resistor-capacitor means connected across said source and operative to switch said solid-state switching means.

2. An electric system according to claim 1 in which said control means is operative between 30° and 150° of each half cycle of alternation of said source.

3. An electric system according to claim 1 in which said control means is operative between 40° and 120° of each half cycle of alternation of said source.

4. An electric system according to claim 1 in which starting means is provided for said lamp.

5. An electric system according to claim 4 in which said starting means includes current limiting means, a pulse transformer having primary and secondary windings, a triggering capacitor connected in series with said primary winding and said current limiting means across said source, solid-state switching means connected across said triggering capacitor and said primary winding operative to discharge said capacitor through said primary winding, said secondary winding connected to said discharge lamp, and adjustable RC means connected across said source to said solid-state switching means for the control thereof.

6. An electric system according to claim 1 in which a resistor is connected across said electronic switch so that said lamp after being started is supplied with ionizing current during the portions of the cycle when said electronic switch is nonconducting.