A new dimming circuit for discharge lamps

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This paper represents a new continuous dimming circuit for fluorescent and High-Intensity Discharge (HID) lamps controlled by inverse parallel connected thyristors with a newly introduced auxiliary step-up transformer. The dimming circuit can not only regulate the light output over range from 100% to 1% continuously, but also can sustain lamp burning steady even if in a lower ambient temperature. These features of the dimming circuit are due to giving a sufficient high reignition voltage to discharge lamps and continuing the lamp current, even though the thyristors are in off period, by the auxiliary step-up transformer.

1. Introduction

Recently, dimmers have been reviewed not only for energy saving but also for various lighting purposes. The development of dimmer for fluorescent lamps has been carried out over more than thirty years¹⁾. And now, one of the promising dimmers is based on the phase control of inverse parallel connected thyristors for a high frequency inverter operating circuit²⁾. On the other hand, for HID lamps, 100% and 50% step dimmer has been used on practice³⁾. The continuous dimmer by means of the above-mentioned phase control has not been reported because of the unstable operation of lamps under low wattage burning and of the deviation of light spectrum, etc. The authors have tried to develop a new dimmer for discharge lamps based on a new principle⁴⁾. The circuit's configuration is similar to a constant wattage discharge lamp operating circuit used widely now except adding an auxiliary transformer. By the function of step-up voltage, the dimming circuit can give a higher voltage for reignition, make the discharge lamp arc stable and then can control the light output over the range from 100% to 1% continuously. In this paper, the principle of dimming circuit, the dimming characteristics of fluorescent lamps and the application to HID lamps, etc., are described.

2. Principle of circuit operation

For the stable ac operation of discharge lamps, the circuit must reignite the lamp without fail and make arc be stabilized. In other words, the reignition voltage must establish the cathode newly and reestablish the plasma conductivity⁵⁾. For meeting the negative characteristic of arc, the

ballast of appropriate capacity is necessary between the source and the lamp. At the dimming of discharge lamps, the decrease of input power causes not only the low temperature but also the extreme reduction of vapor pressure in a tube. Then, the higher reignition voltage must be supplied. In a transition period of dimming control, the time lag among the temperature, the pressure and the input power may result in extinguishing arc. Then, the dimmer for discharge lamps, at least, must have the function as follows, that is, the capability of supplying the high reignition voltage, the avoidance of the current disruption and the security of continuous current flow.

Then, the authors have developed a new dimming circuit considering the above-mentioned factors such as shown in Fig. 1. The high voltage $E_s + E_2$ makes the gradient of electric field large in the tube and the reignition stable. The source voltage E_s supplies power to the discharge lamp and the light output could be controlled by adjusting this power. The high voltage $E_s + E_2$ to the discharge lamp can be supplied by adding a step-up transformer. The power supplied by the voltage E_s can be regulated by the phase control of an inverse parallel thyristor pair or a triac.

Fig. 1 Schematic figure of principle.

For applying this dimming principle to discharge lamps, the methods are different, for example, depending upon whether low pressure lamps or high pressure lamps. Here, for fluorescent lamps, the

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necessary supply current is only a few decimal milliampere, but for high pressure lamps, is necessary about few hundreds milliamperes.

3. Dimming characteristics of fluorescent lamp

3.1 Dimming circuit and its behavior

Figure 2 shows a dimming circuit for fluorescent lamps based on the principle described in Chapter 2. A step-up autotransformer induces the voltage $E_s + E_2$ the terminal of which is connected to the lamp through a reactor L_2 (high impedance). The terminal of the reactor may be connected to the lamp side of thyristors or directly to the lamp, but our various experimental results gave good results on case of the lamp edge. So, we examined the operating characteristics for this circuit configuration. The heater H_1 , H_2 of the fluorescent lamp can be supplied from other terminals of the transformer.

Figure 3 shows an experimental example of operating waveforms. The discharge lamp burns even if phase control angles of thyristors are delayed, because the voltage $E_s + E_2$ applies to the fluorescent lamp. The sufficient power, however, is not given to the lamp since the lamp current is kept to be scarce due to the high impedance. The power is supplied to the lamp when one of the thyristors is fired at the phase angle α through L_1 .

Fig. 2 Dimming circuit for fluorescent lamp.

Fig. 3 Dimming waveforms of fluorescent lamp.

Then, the discharge lamp burns almost all the time and the power controlled by thyristors can dim the fluorescent lamp. These behavior makes the continuous dimming over the wide range possible and the good regulation secure even if in a lower temperature as described in the following.

Table 1 shows circuit constants used in the experiment.

Table 1 Circuit constants at operating fluorescent lamp FLR40S.

Step-up voltage E_2 (V)	Source voltage E_s (V)	Reactor L_1 (H)	Reactor L_2 (H)
0	200	0.895	—
60	200	0.895	11.6

Frequency of source voltage 60 (Hz).

3.2 Control characteristic

Figure 4 shows power control characteristics of a fluorescent lamp FLR40S when the phase control angle α is regulated. It is clear that this method enlarges the scope of control compared with a method without E_2 and L_2 . In the scope where α is above 130 degrees, the characteristic curve is flat because the lamp burns almost by L_2 alone.

Fig. 4 Characteristics of power of fluorescent lamp.

3.3 Burning characteristic in lower ambient temperature

Figure 5 shows the experimental values of luminous flux, where the flux is assumed as 1.0 when the thyristors are in a full conduction state. In its experiment, the lamp was burned in a low temperature box. This proves the stable lamp burning even if the ambient temperature is -5 degrees with the effect of imposed voltage.

3.4 Starting characteristic

The lamp ignited as soon as the power source switched on, regardless of the phase control and/or in a lower temperature. Therefore, it is concluded that E_2 plays an important part for the starting of discharge lamps.

Fig. 5 Characteristics of relative light flux of fluorescent lamp.

4. Application to HID lampies operation

For the dimming of HID lamps, the current flowing through L_2 was approximately 1(A), although its value was about 20 (mA) for fluorescent lamp. These values of current were needed to sustain lamps burning when the thyristors were off.

4.1 Steady state characteristics

Figures 6 and 7 show an experimental circuit for a HID lamp and its operative waveforms. The circuit constants are shown in Table 2. The operating characteristics of mercury lamp were measured with enough intervals after phase control angles were changed every 30 degrees. The mercury lamp was operated on the rated power when the thyristors were in a full conducting state.

Fig. 6 Circuit for HID lamp.

Figure 8(a) shows experimental results of voltage, current, and power of the lamp. The lamp was extinguished in a relatively small control angle α when without E_2 and L_2 . Provided that L_2 was inserted and $E_2=0$ (V), the bypass current flows through L_2 and the minimum value of lamp current becomes greater. But, the lamp voltage does not so scarcely decrease that the minimum lamp power becomes a little larger. On the other hand, provided that $E_2=100$ (V), the current becomes small smoothly and the lamp power is controlled over the range from 400 (W) to 30 (W).

Figure 8(b) shows control characteristics of luminous flux. These results are relative values of luminous level compared with a rated lamp power in a black box. This characteristic of luminous flux is as similar as the power control characteristics shown in Fig. 8(a) and the dimming scope extends to about 1% when $E_2=100$ (V). But, the drop of lighting efficiency, the change of distri-

Fig. 7 Waveforms of voltage and current of mercury lamp.

α : 100 degs.

β : extinguishing angle of thyristor.

Table 2 Circuit constants at operating mercury lamp H400.

Step-up voltage E_2 (V)	Source voltage E_s (V)	Reactor L_1 (mH)	Reactor L_2 (mH)
0	200	86	134
100	200	86	814

Frequency of source voltage 60 (Hz).
Values are decided so that the lamp does not extinguish at 5% variation of source voltage.

(a)

(b)

Fig. 8 Characteristics of mercury lamp.
(a) Voltage, current and power.
(b) Relative luminous level.

bution of light spectrum and the shorter life are inevitable⁵). In our experiments, the lighting color at a low output deviated to the color of a blue tint and the relative values of lamp efficiency decreased rapidly in less than 150 (W) which was given by the calculation based on the experiments, as shown in Fig. 9. The efficiency drop may be caused by the lowered vapor pressure in the output range.

Fig. 9 Luminous efficiency of mercury lamp.

4.2 Behavior in transition period of mercury lamp

On the behavior of mercury lamps under the dimming, the change with time of electric characteristics must be considered as well as that of light flux. Because the characteristics of voltage and current depend upon the vapor pressure of the lamp that has heat inertia.

The transient response at increasing and decreasing of light is shown in Figs. 10(a) and (b), where phase control angles are changed from the full conduction of thyristors to the phase angle α and vice versa. Figure 10(a) shows that the light output varies slowly such the similar way as the starting of lamp operation at the wide range control. The light output reaches practically the final level about three seconds in the control range where α is smaller than 100 degrees. On the other hand, the decreased light output in Fig. 10(b) reaches certain levels in a moment. The levels are nearly final for α smaller than 100 degrees but varies gradually to lower levels for α larger than 120 degrees with time, because the considerable length of time is required until the vapor pressure becomes stable at dimming control. Some fluctuations of light output are observed by a little variation of source voltage and the lamp operation, etc.

Figures 11(a), (b), (c) and (d) show oscillograms of lamp voltage and current in a transition period at the change from the full conduction state of thyristors to off state, that is, the phase control angle $\alpha=180$ degrees. Just after controlled, the lamp voltage increases at first and then decreases with time.

It has been pointed out that the lamp voltage of high pressure sodium lamp is decidedly affected

by the vapor pressure in the tube. It is at the same vapor pressure that the sodium lamp has the negative V-I characteristics such as the lamp voltage increases when the current decreases⁶). The mercury lamp also indicates the same electric characteristics. The thermal energy which relates to the inner pressure of lamp dissipates slowly, because its change is prevented by the vacuum sphere between the arc lamp and the outer bulb. Then, the decreasing control which constrains instantaneously the lamp current to a certain low level results

(a)

(b)

Fig. 10 Transient response of light flux of mercury lamp.

(a) Increasing.
(b) Decreasing.

(a)

(b)

(c)

(d)

Fig. 11 Changes of oscillograms of mercury lamp in a transition period; from full conduction state of thyristors to off state. Vertical axis: lamp voltage 100 (V/div), lamp current 3 (A/div). Horizontal axis: time 2.1 (msec/div). (a) At full conduction. (b) After 1/3 seconds passed. (c) After 3 minutes passed. (d) After 30 minutes passed.

in the increased voltage as shown in Fig.11(b). Figure 12 shows the loci on voltage and current plane when phase control angles are changed from the full conduction to α and vice versa. The decrease path of light flux is a-b-c, and c-d-a is the increase path. The paths of a-b and c-d just after controlled are conjectured and dotted because the change is very quick and is not traced exactly. The intervals of b-c and d-a are 15 and 5 minutes, respectively.

Fig. 12 Characteristics of voltage and current (rms) of mercury lamp at dimming.

These experimental results indicate that the proposed dimming circuit dims a mercury lamp stably without extinguishing, although there is a period when the lamp voltage at decreasing light flux surpasses the steady state voltage.

4.3 Dimming of metal halide lamp

The experimental results are indicated in Fig. 13. The circuit constants are shown in Table 3. The dimming range at $E_2=100$ (V) is superior to the other method. But the lowest value of light flux is relatively large compared with that of mercury lamps. This seems to be due to the reignition voltage lessened by increasing the lamp current, since the metal halide lamp requires a higher reignition voltage compared with the mercury lamp.

Fig. 13 Dimming of metal halide lamp.

Also, the light color varied for a few seconds just after the control angle α was changed. This seems to be transient phenomena based on the distinction of lighting characteristics of each enclosed gases. At decreasing, the light color was observed

Table 3 Circuit constants at operating metal halide lamp M250.

Step-up voltage E_2 (V)	Source voltage E_s (V)	Reactor L_1 (mH)	Reactor L_2 (mH)
0	200	152	44
100	200	152	585

Frequency of source voltage 60 (Hz).

to deviate to that of a red tint. The deviation of light color seems to be different depending upon a sort of enclosed gas and a lamp capacity. This is a serious problem at dimming and must be discussed in the future.

4.4 Dimming of high pressure sodium lamp

The high pressure sodium lamps need a high voltage at the starting of operation as well known. The dimming circuit was started with a LC resonance circuit shown in Fig. 14 and then the branch of C was cut off. The circuit constants used in the experiment are listed in Table 4. Figure 15 indicates the dimming characteristic where the dimming range covers from 100% to 1%. The light color, however, varied to that of a low pressure sodium lamp at low light output.

Fig. 14 Starting circuit for high pressure sodium lamp.

Table 4 Circuit constants at operating high pressure sodium lamp NH250.

Step-up voltage E_2 (V)	Source voltage E_s (V)	Reactor L_1 (mH)	Reactor L_2 (mH)
0	200	125	216
100	200	125	1370

Frequency of source voltage 60 (Hz).

Fig. 15 Dimming of high pressure sodium lamp.

5. Conclusions

As above-mentioned, a new continuous dimming circuit for discharge lamps was examined. By imposing the step-up voltage to lamps through an autotransformer and a reactor, the circuit keeps the lamp current continuous even if the thyristors are in off period and supplies the sufficient high reignition voltage required by discharge lamps even though the lamp current is scarce at dimming. Then, the circuit can regulate the light output over the wide range. The following features were demonstrated experimentally, that is,

(1) the new dimming circuit can control the light output from the rated value to 1%.

(2) the lamp can be reignited stably in a lower ambient temperature.

References

- (1) Matsuda, C., Sakaguchi, T. and Moriyama, H.: J. Illum. Engng. Inst. Jpn. 41-2 (1957) 51.
- (2) Morimoto and Ibuki: J. Illum. Engng. Inst. Jpn. 46-3 (1980) 110.
- (3) Maeda, Shinomiya, Hamahara and Abe: Matsushita Electric Works Technical Report 20 (1980) 25.
- (4) Himei, T., Nakanishi, S., Komatsubara, H. and Uehara, T.: J. Illum. Engng. Inst. Jpn. 67-6 (1983) 235.
- (5) Franke, A., Gungle, W. C., Ring, J. F. and Waymouth, J. F.: Reignition Characteristics of Metal Halide Lamps and Their Effect on Ballast Design. Illum. Engng. 62-4 (1967) 204.
- (6) Takatsuka, K., Takeji, Y., Furukawa, M. and Kokubo, H.: Papers of Technical Meeting on Light Sources and Systems, IEEJ LS-71-6.

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