

A Method and Electronic Control Circuit for Regulating the Operating Behaviour of Gas Discharge Lamps.

The present invention relates to a method and an electronic control circuit, such as for example an electronic control gear, for regulating the operating behaviour, in particular the brightness, of gas discharge lamps.

Figure 5 shows, for example, the construction of a known electronic control gear for controlling a gas discharge lamp 3 as disclosed in EP-A1-0 490 329. EP-A1-0 338 109 has disclosed an electronic control gear similar to the circuit arrangement shown in Figure 1 in which however, in place of heating transformers T1 and T2 illustrated in Figure 5, an ignition or heating capacitor connected in parallel to the lamp coils is used.

In accordance with Figure 5, a rectifier 1, comprising diodes D1-D4 connected to form a bridge circuit, is connected via capacitors C1 and C2 to an a.c. voltage source u_E . The capacitors C1 and C2 are part of a radio interference suppression arrangement. The input a.c. voltage u_E rectified by the rectifier 1 is fed to an inverter 2 which generally comprises two alternately switched semiconductor switches. The inverter 2 converts the link voltage rectified by the rectifier 1 into an output a.c. voltage. Here the output frequency and/or duty factor between the switch-on times of the semiconductor switches of the inverter 2 is/are variable. The output voltage of the inverter is fed to a load circuit comprising a series-resonance circuit consisting of a coil L1 and a capacitor C8, a coupling capacitor C4, heating transformers T1 and T2 for the lamp coils, and the gas discharge lamp 3. The gas discharge lamp 3 is connected via wire conductors to heating transformers T1 and T2. The lamp current i_L flowing across

the gas discharge path of the gas discharge lamp 3 is tapped across a shunt resistor R1 and is normally used as regulating variable for the brightness of the gas discharge lamp 3, i.e. the frequency and/or duty factor of the inverter 2 is regulated as a function of the actual value of the lamp current i_L in order to dim the brightness of the gas discharge lamp 3. The gas discharge lamp 3 is dimmed in that the output frequency f of the inverter 2 is increased. The initial ignition of the gas discharge lamp 3 takes place in that the output frequency of the inverter 2 is adapted to the resonance frequency of the series-resonance circuit comprising the coil L1 and the capacitor C8.

If, however, the lamp current i_L is used as regulating variable, operating disturbances can occur due to excessively long connection lines between the terminals of the electronic control gear and the gas discharge lamp. This manifests in particular in the case of strong dimming, i.e. with low brightness of the gas discharge lamp. These operating disturbances are caused by capacitive influences of the wiring as parasitic capacitances C5 and C6 occur between the lines and earth and a parasitic capacitance C7 occurs between the lines. It can be seen from Figure 5 that the capacitances C5 and C6 between the lines and earth only slightly influence the lamp current i_L measured via the resistor R1 as the capacitive currents flowing across these capacitances C5 and C6 are conducted past the resistor R1 and the capacitance C6 of the line 2 is balanced to earth by the dimming capacitor C3 relative to R1.

On the other hand, the capacitive current produced by the parasitic capacitance C7 between the lines is superimposed upon the lamp current i_L measured via the shunt resistor R1. The resistance equivalent circuit diagram, shown in Figure 6, of the lines with the gas discharge lamp 3 and the parasitic capacitance C7 shows that the shunt resistor R1 is

supplied via the line 2 with the lamp current i_L flowing across the lamp resistor R_{Lampe} and the capacitive current i_{C7} flowing across the parasitic capacitance $C7$. Thus not a purely ohmic current, but a current $i_L + i_{C7}$, shifted in phase relative to the lamp voltage as a function of the parasitic capacitance $C7$, flows across the shunt resistor $R1$.

As already mentioned, the current flowing across the resistor $R1$ is used to regulate the brightness of the gas discharge lamp 3. Here in particular the peak value of this current is measured, which peak value is compared with a predetermined setpoint value which is variable by means of the dimming setting, whereupon optionally the output frequency f or the duty factor d of the switches of the inverter of the electronic control gear is changed. If too high a lamp current is detected via the resistor $R1$, the inverter frequency f is increased so that the voltage across the heating capacitor $C8$ of the series oscillating circuit falls. In this case the gas discharge lamp connected in parallel with the capacitor $C8$ is connected to a lower voltage and thus emits less light.

However, in the case of the known circuit arrangement shown in Figure 5 accurate regulation of the operating behaviour of the gas discharge lamp as a function of the lamp current measured via the resistor $R1$ is not possible, as the peak value of the sum current $i_L(t) + i_{C7}(t)$, (compare Figure 6) i.e. the sum of the lamp current i_L flowing across the coil resistors $R_{Wendel\ 1}$ and $R_{Wendel\ 2}$ and the lamp resistor R_{Lampe} of the gas discharge lamp 3 and the capacitive current i_{C7} flowing across the parasitic capacitance $C7$, is actually measured via the resistor $R1$. As with increasing frequency, i.e. stronger dimming, the capacitive resistance of the parasitic capacitance $C7$ falls and the lamp resistance R_{Lampe} remains constant, in the current measured via the resistor $R1$ the capacitive current component i_{C7} increases in

relation to the purely ohmic lamp current component i_L . This means that, with strong dimming, the electronic control gear detects an excessively high current across the resistor R1 and incorrectly interprets this excessive current as actual value of the lamp current i_L .

This process is illustrated in Figure 8, in which Figures 8a to 8c show different characteristics of the lamp voltage u_L and the current i_{R1} , measured across the resistor R1, for different values of the line capacitance C7. Figure 8a illustrates the ideal situation in which the parasitic line capacitance C7 is very small, so that the capacitive current component i_{C7} of the current measured across the resistor R1 is negligibly small and this current measured across the resistor R1 substantially corresponds to the lamp current i_L . As in this case the current is substantially purely ohmic, the current is not shifted in phase compared to the lamp voltage u_L . As already described, usually the peak value of the current detected across the resistor R1 is measured. This peak value is compared, as actual value I_{ist} , with a predetermined setpoint value I_{soll} . In the example illustrated in Figure 8a the measured peak value I_{ist} corresponds to the setpoint value I_{soll} and therefore no regulation of the brightness of the gas discharge lamp 3 is required. Figure 8b illustrates this process when an average line capacitance C7 occurs between the lines. It can be seen from Figure 8b that, as a result of the capacitive current i_{C7} flowing across the line capacitance C7, not only is the current i_{R1} also shifted in phase relative to the lamp voltage u_L but the measured peak value I_{ist} is also distinctly increased compared to the situation illustrated in Figure 8a. Therefore in the case of the signal characteristic illustrated in Figure 8b the electronic control gear would recognise that the measured peak value I_{ist} is greater than the measured setpoint value I_{soll} . The electronic control gear would therefore attempt

to reduce this increased current again by increasing the frequency across the inverter 2, although this is opposed by the capacitive resistance - falling due to the rising frequency - of the parasitic capacitance C_7 , with the result that the capacitive component i_{C_7} of the current i_{R_1} measured across the shunt resistor R_1 is increased. This cycle finally leads to the extinguishing of the lamp, although the extinguishing of the gas discharge lamp 3 by the electronic control gear cannot be ascertained by measurement of the current i_{R_1} flowing across the resistor R_1 as a capacitive current i_{C_7} also flows when the lamp is extinguished via the parasitic capacitance C_7 . Figure 8c illustrates corresponding signal characteristics for the occurrence of a high line capacitance value between the lines which connect the gas discharge lamp 3 to the electronic control gear. In the case of the signal characteristics illustrated in Figure 8c, due to the distinctly increased capacitive current component i_{C_7} relative to the lamp current i_L , the resultant sum current i_{R_1} is distinctly increased again. The measurement error occurring as a result of the superimposition with the capacitive current i_{C_7} is greatest in the example illustrated in Figure 8c.

It will be apparent from the previous description that due to the capacitive influences of the wiring, correct dimmer operation of the gas discharge lamp is not possible since, particularly in the case of strong dimming of the gas discharge lamp, the capacitive current i_{C_7} flowing across the line capacitance C_7 is distinctly superimposed upon the lamp current i_L actually to be measured. The previously employed method, in which the peak value of the current i_{R_1} flowing across the resistor R_1 is measured, is therefore too inaccurate in the case of electronic control gears covering wide dimming ranges (between 100% and 1% brightness). For different cable types and different cable lengths l and for different operating frequencies f , Figure 7 shows the value

of the parasitic line capacitance C_7 occurring between the lines. It can be seen from Figure 7 that on the one hand the parasitic capacitance C_7 rises with increasing cable length l and on the other hand a larger line capacitance occurs at a lower operating frequency f . The measurement results shown in Figure 7 indicate that, for the line capacitance to have a small influence, light manufacturers would need to take into account a specified, maximum permissible length of the wiring. However, presetting of a maximum permissible wiring length is undesirable.

Therefore the object of the invention is to provide a method and a control circuit, in particular for the implementation of the method, for regulating and/or measuring the operating state of gas discharge lamps in which accurate regulation and/or measurement of the operating state is possible and it is unnecessary to take into account the wiring length between the gas discharge lamp and a series-connected electronic control gear.

This object is achieved with regard to the method by the features of Claims 1 and 2 and with regard to the electronic control circuit by the features of Claim 12.

In accordance with the invention it is proposed that only the active component of the lamp current be evaluated. In this way the influence of the capacitive current flowing across the parasitic line capacitance is eliminated and accurate regulation and/or measurement of the operating state is possible without the need to take the line length into account. In particular, the connected lamp can be accurately dimmed over wide dimming ranges.

Further advantageous developments of the invention are described in the sub-claims.

In the following the invention will be explained in detail in the form of preferred exemplary embodiments. In the drawing:

- Figure 1 shows current- and voltage characteristics of a first exemplary embodiment according to the invention;
- Figure 2 shows current- and voltage characteristics in explanation of a second exemplary embodiment according to the invention;
- Figure 3 schematically illustrates an electronic control gear according to the invention;
- Figures 4a and 4b are diagrams comparing the methods according to the invention with the known regulation method;
- Figure 5 illustrates a known electronic control gear;
- Figure 6 is a simplified resistance equivalent circuit diagram of the lines shown in Figure 5, the lamp and the parasitic line capacitance;
- Figure 7 shows example values of the line capacitance for different cable types, cable lengths and operating frequencies and
- Figure 8 shows current- and signal characteristics in explanation of the known regulation method.

Figure 1 illustrates characteristics of the current i_{R1} measured via the resistor $R1$ and of the lamp voltage u_L for different values of the line capacitance $C7$ shown in Figure 5. Figure 1a shows the signal characteristics for a very

small line capacitance value C_7 , so that the capacitive current i_{C7} superimposed upon the actual lamp current i_L and flowing across the line capacitance C_7 is negligibly small. In this case no phase shift occurs between the current i_{R1} measured across the resistor $R1$ and the lamp voltage u_L , and the current measured across the resistor $R1$ ideally corresponds to the lamp current i_L actually to be measured. In this respect the signal characteristics illustrated in Figure 1a do not differ from the signal characteristics illustrated in Figure 8a. Figure 1b shows signal characteristics for the situation in which an average line capacitance C_7 forms between the lines shown in Figure 5, so that the current measured across the resistor $R1$ is shifted in phase in relation to the lamp voltage u_L and leads the lamp voltage u_L . In accordance with the invention, it is proposed that the current flowing across the resistor $R1$ be measured only when the lamp voltage u_L has reached its peak value. For a purely sinusoidal current i_{R1} , the following formula thus applies:

$$I_{ist} = \hat{I}_{ist} \cdot \sin(\alpha + \beta) \quad (1)$$

wherein I corresponds to the peak value of the current measured across the resistor $R1$. However, for purely sinusoidal variables the following also applies:

$$\alpha = \pi/2 \quad (2)$$

As:

$$\sin(\alpha + \pi/2) = \cos(\alpha) \quad (3)$$

formula (1) is simplified into

$$I_{ist} = \hat{I} \cdot \cos \beta \quad (4).$$

For the extreme values $\beta = 0^\circ$ and $\beta = 90^\circ (\pi/2)$, i_{R1} thus assumes the values $\hat{I}$ and zero.

When the peak value $\hat{I}$ of the current i_{R1} measured across the resistor $R1$ is known, by measuring the phase difference between the current i_{R1} and the lamp voltage u_L it is thus possible to calculate the unadulterated actual value I_{ist} at the time at which the lamp voltage u_L has reached its positive peak value. Figure 1c illustrates corresponding characteristics for a very large value of the line capacitance $C7$, so that the current i_{R1} measured across the resistor $R1$ is distinctly increased and is distinctly shifted in phase compared to the lamp voltage u_L . Even in the event of such a strong influence of the capacitive current i_{C7} flowing across the parasitic capacitance $C7$, in the method according to the invention the actual value I_{ist} corresponding to the actual lamp current i_L is always measured and therefore accurate regulation of the lamp brightness is possible even with strong dimming.

The method illustrated in Figure 1 calculates the actual value I_{ist} in fault-free manner only for purely sinusoidal current characteristics. However, this method can also be employed for other periodic curve characteristics although a uniform error always occurs.

Figure 2 shows the corresponding current- and voltage characteristics in explanation of the second exemplary embodiment according to the invention. Figure 2a again shows the characteristics for a negligible capacitive current across the line capacitance $C7$, while Figures 2b and 2c show the signal characteristics for an average line capacitance and a very high line capacitance.

In accordance with the second exemplary embodiment of the method according to the invention, it is proposed that the

mean value of the current i_{R1} measured across the resistor $R1$ be formed during a half wave of the lamp voltage u_L . Thus the arithmetic mean value of the current i_{R1} during a half wave of the lamp voltage u_L is calculated as actual value I_{ist} of the lamp current i_L which serves as regulating variable for the frequency and/or duty factor of the inverter. It can be seen from Figure 2 that, as a result of the current-voltage shift caused by the line capacitance $C7$, the thus measured mean value, i.e. I_{ist} , follows the cosine of the shift angle β illustrated in Figure 1b during the positive half wave of the lamp voltage u_L . Thus

$$I_{ist} \sim \cos \beta \quad (5).$$

For the extreme value $\beta = 0^\circ$, the whole of the shaded area above the zero line is the gauge of the actual value I_{ist} of the lamp current i_L while for $\beta = \pi/2$, the areas above and below the zero line are equal in size and thus the arithmetic mean value, i.e. I_{ist} , is zero. Between these two extreme values for I_{ist} there always remains a positive area component, and thus a corresponding mean value, which is evaluated as actual value I_{ist} of the lamp current i_L and is used as regulating variable for the brightness of the gas discharge lamp.

It can be seen from Figure 2 that, due to the arithmetic mean value formation, it is possible to eliminate the capacitance current component i_{C7} produced by the parasitic line capacitance $C7$, whereby accurate dimming of the gas discharge lamp over a wide dimming range is possible. In particular, in the case of the second exemplary embodiment of the method according to the invention illustrated in Figure 2 it is also possible to arrive at the correct actual value I_{ist} as regulating variable for the inverter by measuring the phase shift between the current i_{R1} and the lamp voltage u_L .

A common feature of the methods illustrated in Figures 1 and 2 is that always only the actual active component of the lamp current is evaluated. With a complex lamp current this means that only the real component of the lamp current is used for the regulation of the operating state.

Figure 3 is a simplified block circuit diagram of an electronic control gear according to the invention which is used in particular for the implementation of the method according to the invention. In addition to the circuit elements already shown in Figure 5, a device 4 for measuring the voltage u_L and the current i_{R1} flowing across the resistor R1 is additionally provided. A measured variable proportional to the lamp voltage u_L is tapped between the resistors R4 and R5 and fed to the device 4. As already described with reference to Figure 5, via the shunt resistor R1 a measured variable proportional to the lamp current i_L is tapped and fed to the device 4. On the basis of the supplied signal characteristics, the device 4 calculates the actual active component of the lamp current, i.e. in accordance with the previously described exemplary embodiments of the method according to the invention the device 4 calculates the actual value I_{ist} of the lamp current I_L corrected in relation to the capacitive component i_{C7} . This actual value I_{ist} is fed to a device 5 which subjects the calculated actual value I_{ist} to a setpoint-actual comparison with a setpoint value, i.e. a predetermined setpoint value I_{soll} . As a function of this setpoint-actual comparison, the frequency f and/or duty factor d of the inverter 2 is changed in order to regulate the brightness of the gas discharge lamp 3. Alternatively however, it can also be provided that the actual value I_{ist} calculated by the device 4 be fed directly to the inverter 2.

It should be noted that u_L and i_L can also be measured by a device separate from the device 4. Equally, one or several

other reference variables can be used instead of u_L . For example, the actuation time(s) of the switches of the inverter 2 could also be used as reference variable as the current- and voltage characteristic of a given circuit arrangement is predictable. Thus for example it can be specified that the current be measured after a certain time interval following the switching-on of the one inverter switch. If the time interval is selected such that the current measurement takes place at the time of the voltage maximum, the measured current corresponds to the actual active component of the lamp current. It is also possible to form the mean value of the measured current between the switching-on and off of a switch of the inverter 2.

Figures 4a and 4b are diagrams comparing the known regulation method with the regulation method according to the invention. Figure 4a illustrates the lamp power as a function of the value of the parasitic line capacitance. It can be seen that, as already described, the characteristic referenced c and corresponding to the known regulation method is highly dependent upon the line capacitance, whereas the characteristics referenced a and b of the first and second exemplary embodiment respectively of the method according to the invention are virtually independent of the line capacitance. It can also be seen from Figure 4b that in the case of the known regulation method the operating frequency is distinctly influenced by the line capacitance (compare characteristic c), while in the case of the methods according to the invention an operation which is virtually independent of the line capacitances is possible (compare characteristics a and b). It should be noted that the characteristics illustrated in Figures 4a and 4b have been shown for constant resistance values of the lamp. For larger lamp resistance values it was found that the characteristics a and b according to the invention are

downwardly displaced, while the characteristics c of the known regulation method remain substantially unchanged.

Finally it should be noted that the regulation methods according to the invention are additionally advantageous when rapid ignition recognition is to take place. Such rapid ignition recognition is particularly advantageous when the gas discharge lamp is to be dimmed in its brightness as rapidly as possible after its ignition. Especially when a lamp is to be started with low brightness, the capacitive current component i_{C7} produced by the parasitic line capacitance $C7$ is problematic since, in order to be able to increase the output frequency of the inverter for dimming the gas discharge lamp immediately after the ignition of the gas discharge lamp, upon the detection of a current flowing across the shunt resistor $R1$ it is concluded that the gas discharge lamp has successfully ignited. In the known regulation method, errors can arise in that the capacitive current component i_{C7} flows across the capacitive line capacitance $C7$ even when the gas discharge lamp has not ignited, which could be incorrectly interpreted as the lamp current produced by the ignition of the gas discharge lamp. As however, by the use of the regulation methods according to the invention, the measured actual value now is virtually independent of the influences of the line capacitance $C7$, on the basis of the actual value of the current across the resistor $R1$ calculated in accordance with the invention it is possible to reliably conclude, upon the overshooting of a precisely definable threshold, that the gas discharge lamp has successfully ignited.

The method and the control circuit according to the invention can also be applied to the electronic control gear described in EP-A1-0 338 109 referred to in the introduction, which comprises an ignition- and heating capacitor arranged in parallel to the gas discharge path of

the lamp. In spite of the parallel connected heating capacitor, in accordance with the invention the actual lamp current can be measured. The consequence of this is that, in the non-dimmable arrangement described in EP-A1-0 338 109, component tolerances and environmental influences (such as e.g. the environmental temperature) upon the lamp which would affect the regulation accuracy, are eliminated by the use of the invention.

In general the invention, and the advantages thereof explained in detail in the foregoing, can be applied both to dimmable and to non-dimmable devices. In particular, the device can also be applied to electronic control gears which comprise externally commutated inverters and which thus require to be regulated.

Claims

1. A method for regulating the operating behaviour of at least one gas discharge lamp (3), which is operated in particular via an electronic control gear, as a function of a regulating variable (I_{ist}), characterised in that the regulating variable (I_{ist}) is based on the active component of the lamp current (i_L) or a variable corresponding to the active component.
2. A method for measuring and/or evaluating the operating state of at least one gas discharge lamp (3), which is operated in particular via an electronic control gear, by measuring at least one variable corresponding to the lamp current (i_L), characterised in that for the measurement and/or evaluation of the operating state, the active component of the lamp current (i_L) or a variable corresponding to the active component is determined.
3. A method according to Claim 1 or 2, characterised in that the active component of the lamp current (i_L) is the real component of the lamp current (i_L).
4. A method according to one of Claims 1 to 3, characterised in that the frequency (f) and/or duty factor (d) of an a.c. voltage source (2) connected to the gas discharge lamp (3) is changed as a function of the active component.
5. A method according to one of Claims 1 to 4, characterised in that the lamp current (i_L) is measured at the time at which the lamp voltage (u_L) has reached its positive peak value and that the actual value of the lamp current (I_{ist}) acquired therefrom is used as regulating variable.



6. A device according to one of Claims 1 to 4, characterised in that during a half wave of the lamp voltage (u_L) the arithmetic mean value of the lamp current (i_L) is formed, and that the actual value of the arithmetic mean value of the lamp current (i_L) is used as regulating variable.
7. A method according to Claim 5 or 6, characterised in that the lamp current (i_L) is measured via a shunt resistor (R_1) connected in series with the gas discharge lamp (3).
8. A method according to one of Claims 5 to 7, characterised in that the brightness of the gas discharge lamp (3) is regulated.
9. A method according to one of the preceding claims, characterised in that the variable corresponding to the active component of the lamp current (i_L) is derived from the actuation of at least one controllable switch of an electronic control gear which serves to operate the at least one gas discharge lamp (3).
10. A method according to Claim 9, characterised in that following the switching-on of the at least one controllable switch of the electronic control gear, the current is measured at the time of the voltage maximum and is used as the variable corresponding to the active component of the lamp current (i_L).
11. A method according to Claim 9, characterised in that between the switching-on and switching-off of the at least one controllable switch, the mean value of the current is formed and is used as the variable corresponding to the active component of the lamp current (i_L).



12. An electronic control circuit for controlling at least one gas discharge lamp (3), in particular for implementing the method according to one of the preceding claims, with a voltage source (2) which is variable in its output frequency (f) and/or duty factor, and with a device for measuring the lamp voltage (u_L) and the lamp current (i_L), characterised in that a device (4) is provided for determining the active component of the lamp current (i_L).

13. An electronic control circuit according to Claim 12, characterised in that the device (4) for determining the active component of the lamp current (i_L) calculates a regulating variable, which is a function of the active component, for the operating behaviour, in particular the brightness, of the gas discharge lamp.

14. An electronic control circuit according to Claim 13, characterised in that the regulating variable is the actual value (I_{ist}) of the measured lamp current (i_L) at the time at which the lamp voltage (u_L) has reached its positive peak value.

15. An electronic control circuit according to Claim 13, characterised in that the regulating variable is the actual value of the arithmetical mean value of the measured lamp current (i_L) during a half wave of the lamp voltage (u_L).

16. An electronic control circuit according to one of Claims 13 to 15, characterised in that the variable voltage source is an inverter (2) and that the regulating variable can be fed to the inverter (2) either directly or via a device (5) for the setpoint-actual comparison of the actual value with a setpoint value.

17. An electronic control circuit according to Claim 16, characterised in that the frequency (f) and/or duty factor



(d) of the inverter (2) can be changed as a function of the regulating variable.

18. An electronic control circuit according to one of Claims 12 to 17, characterised in that the device for measuring the lamp current (i_L) is a shunt resistor (R_1).