

The invention relates to an electronic ballast in accordance with the preamble of the patent claim.

Electronic ballasts of this type are disclosed, for example, in DE-A1-3,709,004. If such an electronic ballast is to be used to dim a fluorescent lamp within wide limits, difficulties arise, in particular, at the settings $< 10\%$ of the nominal lighting current. Fluorescent lamps have large tolerances with regard to their electric characteristics, react sensitively to temperature variations and are subject to ageing phenomena. When a fluorescent lamp is dimmed towards low values, there is therefore the risk that the fluorescent lamp will be extinguished because the discharge is broken off.

In the reference specified, the controller dims the fluorescent lamp via its discharge current. However, this principle fails at the settings $< 10\%$ of the nominal lighting current, since the differential current transformer required for this purpose would have to be completely free of stray field. In the dimmed setting of 1% , a stray flux of the differential current transformer of only 1% of the main flux would falsify the measurement result by approximately 100% .

As disclosed, for example, in DE-A1-2,544,364 A1, instead of controlling the discharge current of the fluorescent lamp the control can also be performed via the lamp power. This has the disadvantage, however, that only the sum of the lamp power and filament heating power can be controlled. The filament heating power depends strongly on the tolerance-affected filament resistance. As a result, this type of control can also be applied only conditionally in the case of dimmed settings $< 10\%$ of the nominal lighting power. For example, in a dimmed setting of 1% of the nominal lighting power the lamp power of conventional fluorescent lamps which is to be controlled is approximately 0.5 W , whereas the heating power is approximately 4 W . A satisfactory synchronism between a plurality of fluorescent lamps thus cannot be guaranteed in this way given settings $< 10\%$.

Furthermore, a dimming circuit for high-pressure lamps is disclosed in US-A-3,989,976. In addition to a ballast, which by contrast with modern electronic ballasts for low-pressure lamps such as fluorescent lamps, however, operates not at high frequency in the range of more than 20 kHz but at system frequency, this known circuit has an auxiliary control loop. On the basis of the AC operating voltage rising at the high-pressure lamp, this auxiliary control loop detects a tendency to extinction of the lamp arc. The auxiliary control loop is constructed such that the increased AC operating voltage occurring upon dimming is automatically compensated by feeding the lamp increased power via the ballast. This is accomplished by providing that the normal drive of the ballast, which is tuned to the cycle of the AC supply voltage, is neutralized in this critical operating state and the control is referred instead to the output signal of a sampling circuit which evaluates the lamp operating voltage.

The known solution is adapted to the typical lighting current/voltage characteristic for high-pressure lamps, which rises steeply with falling lamp lighting current. However, in low-pressure lamps the AC operating voltage is not dependent in this way on the lamp lighting current. Superficially, the lamp operating voltage in this type of lamp is virtually independent of the lamp lighting current, but a more accurate view reveals that with decreasing lamp lighting current after passing through a maximum it falls again precisely in the critical region of low lamp lighting currents. Feeding back the lamp operating voltage to the control loop of the electronic ballast is therefore incapable of stabilizing this control loop, even taking into account that it would be necessary to adapt to a reduction of the lamp operating voltage. The reason for this is that because of the maximum which occurs at low lighting current values the lighting current/voltage characteristic is not unique.

The object of the invention is to specify in the

case of a dimable electronic ballast of the type mentioned at the beginning and independently of whether the fluorescent lamp is controlled by discharge current or by power, a solution which permits reliable dimming in
5 conjunction with a low extra outlay even in the case of dimmed settings below 10% of the nominal lighting current as far as down to less than 1%.

This object is achieved according to the invention by means of the features specified in the character-
10 izing part of Patent Claim 1.

The invention is based on the finding that it is principally the discharge current which changes upon dimming of a fluorescent lamp, whereas the lamp operating voltage remains the same - at least in terms of order of
15 magnitude. This means that the voltage/current ratio, that is to say the resistance of the discharge path, becomes ever larger with decreasing brightness and ultimately tends towards infinity when the discharge breaks off.

Irrespective of which control of the fluorescence lamp is used, a fluorescent lamp can therefore still be reliably operated at 1% of its nominal lighting current when the discharge resistance is additionally monitored and the controlled variable derived therefrom is used for
20 the purpose of correcting the controlled variable for the controller in the lower range of dimming.

This additional control as a function of the discharge resistance of the fluorescent lamp has, moreover, substantial advantages. It transpires that given
30 otherwise different electrical properties, argon lamps and krypton lamps of the same length have approximately the same discharge resistance for dimmed settings around 1% of the nominal lighting current. There is therefore no need to adapt this special control to the lamp type.

35 A further advantage of this control as a function of the discharge resistance resides in that the ballast can detect whether the lamp is burning without requiring optoelectronic devices or a differential current transformer for detecting the lamp current for this purpose.

This can be used, for example, to control the preheating phase of the fluorescent lamp given electronic ballasts intended for warm starting, since premature ignition of the fluorescent lamp can be detected and a switch can be made immediately from preheating to operation.

Expedient embodiments of the subject-matter according to Patent Claim 1 are specified in the further Patent Claims 2 to 10.

Exemplary embodiments of the invention are described below in detail with the aid of the drawing, and in this case the figures, which serve the purpose of a more detailed explanation of the invention, have the following significance.

Fig. 1 shows a first exemplary embodiment of an electronic ballast which can be dimmed within wide limits, the auxiliary controlled variable depending on the discharge resistance of the fluorescent lamp being obtained from the potential of a lamp electrode,

Fig. 2 shows a further preferred exemplary embodiment of an electronic ballast which can be dimmed within wide limits, in which the auxiliary controlled variable depending on the discharge resistance of the fluorescent lamp is obtained from a low-frequency component of the AC operating voltage of the fluorescent lamp,

Fig. 3 shows a development of the embodiment according to Figure 1, and

Fig. 4 shows an embodiment of the auxiliary circuit used in the circuits according to Figure 3.

The dimable electronic ballast represented in Figure 1 partially in the form of a block diagram essentially comprises an inverter WR which is connected on the output side to a load circuit. The load circuit comprises in this case the series circuit of a lamp inductor L1 and a fluorescent lamp LL connected in parallel with an ignition capacitor C2. The inverter WR uses a half-bridge circuit composed of two series-connected switches T1, T2 constructed as power transistors, and a half-bridge

capacitor C1 which is connected in parallel with a discharge resistor R1.

5 The common tie point of the half-bridge capacitor C1, the discharge resistor R1 and one of the electrodes of the fluorescent lamp LL is denoted by A, and the tie point of the other electrode and the lamp inductor L1 is denoted by B. The switches T1 and T2 of the half-bridge circuit are driven by an oscillator O which, for its part, is connected via its control input to the output of
10 a controller RR.

Upstream of the control input of the controller RR is a summer SR which has comparator properties and to whose three inputs a desired value SW, an actual value IW and an auxiliary controlled variable HMG are fed. Adding
15 the actual value IW, the desired value SW and the auxiliary control variable HMG correctly in terms of sign yields a magnitude for the system deviation RAG which is fed from the output of the summer SR to the control input of the controller RR. In the exemplary embodiment according to Figure 1, the desired value SW, the actual value
20 IW and the auxiliary controlled variable HMG are DC voltages which together yield the system deviation RAG, which likewise represents a DC voltage.

The power supply for the inverter WR is usually
25 in the form of a DC voltage which is obtained from the AC supply voltage, and is specified in Figure 1 as the intermediate circuit DC voltage Uzw. This intermediate circuit voltage is applied to the series circuit of the two switches T1 and T2. The half-bridge capacitor C1 and the discharge resistor R1 are connected, for their part,
30 to the positive terminal of the intermediate circuit DC voltage Uzw. The auxiliary controlled variable HMG is tapped at the tap of a voltage divider which is formed from the resistors R2 and R3 and is connected, for its
35 part, from the tie point A to the negative terminal of the intermediate circuit DC voltage Uzw.

The desired value SW representing a reference voltage is usually generated from a DC voltage of adjustable magnitude, which is not represented in Figure

1 or the remaining figures. The actual value I_W , which likewise represents a DC voltage, is proportional either to the discharge current flowing through the fluorescent lamp LL or, instead, to the lamp power. It can be
5 obtained in a known way via a differential current transformer or via a current/voltage measurement in the region of the load circuit. A representation of the circuit of such an actual value detector has been dispensed with in Figure 1, and the same holds for the
10 remaining figures.

Given the usually symmetrical drive of the switches T1 and T2 of the half-bridge, half the intermediate circuit DC voltage U_{zw} , superimposed by the AC operating voltage of the fluorescent lamp LL, is
15 established at the tie point B when the fluorescent lamp LL is alight. The half-bridge capacitor C1 and the discharge resistor R1, which is connected in parallel with it, are usually so large that half the intermediate circuit DC voltage U_{zw} is likewise established at the tie
20 point A given the nominal lighting current of the fluorescent lamp. In other words, the discharge resistor R1 is significantly larger than the discharge resistance of the fluorescent lamp in this operating condition, so that the discharge of the half-bridge capacitor C1
25 effected by the discharge resistor R1 can be neglected in practice. The high-frequency lamp current effects only a slight voltage drop across the half-bridge capacitor C1.

If, however, proceeding from the nominal lighting current, the fluorescent lamp LL is dimmed down to the
30 point at which the discharge threatens to break off, the discharge resistance of the fluorescent lamp LL becomes so large that the discharge resistor R1 can partially discharge the half-bridge capacitor C1. The result of this is a rise in the potential at the tie point A and
35 likewise in the auxiliary controlled variable HMG at the tap of the voltage divider R2/R3, which has been divided down thereby. The auxiliary controlled variable HMG therefore opposes a further lowering of the lamp power, and via the controller RR prevents the discharge from

being broken off undesirably. The change described in the auxiliary controlled variable HMG has a noticeable effect only in the immediate vicinity of the lower limit of the range of dimming of the fluorescent lamp LL, because it is only in this region that the discharge resistance of the fluorescent lamp and thus also the potential at the tie point A rise noticeably.

This way of deriving the auxiliary controlled variable HMG from the magnitude of the discharge resistance of the fluorescent lamp LL by measuring a DC voltage assumes that no inherently possible rectifier effects occur in the fluorescent lamp. For example, such a rectifier effect can occur when large differences are present in the emission capability of the electrodes of the fluorescent lamp LL. If the dependence of the measurement of DC voltage, and thus of the generation of the auxiliary controlled variable HMG on such a rectifier effect are to be excluded, the auxiliary controlled variable HMG can also be derived from an alternating voltage. A corresponding exemplary embodiment is shown in Figure 2.

Derivation of the auxiliary controlled variable HMG is performed in this case by superimposing a low-frequency AC voltage on the fluorescent lamp LL with the high-frequency AC operating voltage. For this purpose, the fluorescent lamp LL is additionally connected to the AC supply voltage UN via coupling elements KE1, for example in the form of coupling resistors Rk. The low-frequency component, thereby occurring at the fluorescent lamp LL, of the AC operating voltage is then fed via further coupling elements KE2, which block the high-frequency component of the AC operating voltage as well as the DC component, to a rectifier GL, downstream of which a filter element SG is connected for the purpose of smoothing the rectified low-frequency component of the AC operating voltage. The output of the filter element SG is connected in parallel to the voltage divider R2/R3, which is already known from Figure 1 and at whose tap the auxiliary controlled variable HMG is available. The

coupling elements KE2 comprise the series circuit of a filter inductor L_s and a filter capacitor C_s .

Since the effectiveness of the auxiliary control variable HMG is of interest only at the lower limit of the range of dimming of the fluorescent lamp LL, a threshold in the form of a zener diode D1, for example, can be additionally integrated into the connecting path between the tap of the voltage divider R2/R3 and the summer SR, as shown in Figure 3. The auxiliary control which prevents the discharge from breaking off starts suddenly only when the auxiliary controlled variable HMG at the tap of the voltage divider R2/R3 has become so large, given a dimmed setting of, for example, one or two percent of the nominal lighting current, that the zener diode enters its low-resistance state. The behaviour of the controller in the range of dimming above this threshold is then not influenced by this auxiliary control, and this is sometimes desired. The zener diode D1 is illustrated in the circuit diagram according to Figure 3. The circuit of Figure 3 represents a development of the circuit according to Figure 1. Apart from the zener diode D1 in the connecting path between the tap of the voltage divider R2/R3 and the summer SR, the circuit according to Figure 3 differs from the circuit according to Figure 1 by an auxiliary circuit ZS. This auxiliary circuit ZS generates a further auxiliary controlled variable HMG1 which is superimposed on the auxiliary controlled variable HMG in a manner having the same effect. The control rate of the auxiliary control is thereby substantially increased.

The change in the discharge resistance given a dimming operation of the fluorescent lamp LL in the direction of decreasing brightness, results in a relatively slow change in the potential at the tie point A, because a large time constant of the half-bridge capacitor C1 and discharge resistor R1 is prescribed by the overall circuit. Hunting can therefore occur given unfavourable dimensioning. However, the dynamic behaviour of the controller can be substantially improved by the

auxiliary circuit ZS, because the influence of this large time constant can be reduced thereby. Given a lamp power greatly reduced to values below 10% of the nominal power, the AC operating voltage of the fluorescent lamp LL decreases with the lamp power. The auxiliary circuit ZS exploits this by generating from the AC operating voltage a DC voltage which is proportional to the AC operating voltage and is superimposed correctly in terms of sign on the auxiliary controlled variable HMG as a further auxiliary controlled variable HMG1 for the purpose of the desired control.

A preferred embodiment of the auxiliary circuit ZS according to Figure 3 is represented in Figure 4. It comprises between the tie point B and the negative terminal of the intermediate circuit DC voltage Uzw of the series circuit composed of a capacitor C3 and a voltage divider R4/R5 formed from resistors R4 and R5. The component of the AC operating voltage divided down at the resistor R5 is then rectified via a diode D2, and the rectified operating AC voltage is fed to the parallel circuit composed of a capacitor C4 and a resistor R6. The change in the rectified AC operating voltage becomes effective at the capacitor C4 and is fed via the capacitor C5 to the resistor R3 of the voltage divider R2/R3 as the further auxiliary controlled variable HMG1.



Patent claims

1. Electronic ballast having an inverter (WR) which is constructed in a switching bridge and to which there is connected on the output side at least one load circuit
5 which has a lamp inductor (L1) and, situated in series therewith, a parallel circuit composed of a fluorescent lamp (LL) and an ignition capacitor (C2), and having a controlling system (SR, RR) which drives the inverter and, by means of a desired/actual value comparison and a
10 system deviation (RAG) resulting therefrom permits both continuous operation with stabilized brightness and dimming of the fluorescent lamp as a function of an actual value (IW), which is derived from a measured instantaneous value of the lamp power or the lamp
15 current, as well as of a corresponding desired value (SW), which is referred to the lamp power or the lamp current and is of adjustable level, characterized in that there is provided for the purpose of measuring the instantaneous discharge resistance of the fluorescent
20 lamp an auxiliary measuring circuit (Uzw, R1, R2, R3 or Un, KE1, KE2, R2, R3) which derives from this discharge resistance, which increases with decreasing brightness of the fluorescent lamp, an auxiliary controlled variable (HMG) which is superimposed on the system deviation
25 in the controlling system.
2. Electronic ballast according to Claim 1, characterized in that in addition to a controller (RR), which drives the inverter (WR), the controlling system (SR, RR) has a summer (SR) to which the desired value (SW), the
30 actual value (IW) and the auxiliary controlled variable (HMG) are fed in the form of DC voltages and which, adding up these DC voltages correctly in terms of sign, forms as output voltage the superimposed system deviation (RAG) which is fed to the controller as controlled
35 variable.
3. Electronic ballast according to Claim 1 or 2, in which the inverter (WR) has two controlled switches (T1, T2) which are situated in series with one another and whose common tie point forms the inverter



output and is connected via the lamp inductor (L1) to an electrode of the fluorescent lamp (LL), in which this series circuit composed of the controlled switches is connected to an intermediate circuit DC voltage (Uzw) which forms the power supply of the inverter and is derived from an AC supply voltage (Un), and in which a terminal of this series circuit composed of the controlled switches is connected via a half-bridge capacitor (C1) to the second electrode of the fluorescent lamp (LL), characterized in that the auxiliary measuring circuit (Uzw, R1, R2, R3) comprises a discharge resistor (R1) connected in parallel to the half-bridge capacitor (C1) and a voltage divider (R2/R3) which is formed from two further resistors (R2 and R3, respectively) and which is connected, on the one hand, to the electrode of the fluorescent lamp that is connected to the half-bridge capacitor, and is thus assigned via this capacitor to one terminal (+) of the intermediate circuit voltage, and which is connected, on the other hand, directly to the other terminal (-) of the intermediate circuit voltage and which has a centre tap which forms the output of the auxiliary measuring circuit and is connected to the input of the controlling system (SR, RR).

4. Electronic ballast according to Claim 3, characterized in that there is provided between the electrode of the fluorescent lamp (LL) that is connected via a common tie point (B) to the lamp inductor (L1) and the other terminal (-) of the intermediate circuit DC voltage (Uzw) an additional circuit (ZS) for forming a further auxiliary controlled variable (HMG1) which is derived in the form of a DC voltage from the AC operating voltage of the fluorescent lamp and fed at the centre tap of the voltage divider (R2/R3) to the auxiliary controlled variable (HMG) derived from the discharge resistance of the fluorescent lamp in such a way that it is superimposed on this auxiliary controlled variable derived from the discharge resistance of the fluorescent lamp and supports the voltage variation thereof in an



amplifying manner in the lower range of dimming.

5. Electronic ballast according to Claim 4, characterized in that the additional circuit (ZS) for measuring the AC operating voltage of the fluorescent lamp (LL) has a series circuit composed of a further capacitor (C3) as well as two further resistors (R4, R5) likewise forming a voltage divider, this series circuit being arranged between the tie point (B) of the lamp inductor (L1) having the assigned electrode of the fluorescent lamp and the other terminal (-) of the intermediate circuit DC voltage (Uzw), and in that furthermore [lacuna] between a centre tap of this voltage divider (R4/R5) of the additional circuit and the other terminal (-) of the intermediate circuit DC voltage in a manner connected in parallel to the corresponding resistor (R5) of this voltage divider a π four-terminal network which has shunt elements composed of a parallel circuit of a further capacitor (C4) and a further resistor (R6) and has series elements formed from a series circuit of a diode (D2) connected to the centre tap of the voltage divider (R4/R5) and a further capacitor (C5), a component voltage tapped at the centre tap of the voltage divider of the additional circuit and proportional to the AC operating voltage of the fluorescent lamp being rectified and filtered by this π four-terminal network, which outputs it at the free terminal of the series element capacitor (C5) as the further auxiliary controlled variable (HMG1) derived from the AC operating voltage.

6. Electronic ballast according to one of the preceding claims, characterized in that the value of the discharge resistor (R1) connected in parallel with the half-bridge capacitor (C1) is dimensioned in terms of its order of magnitude in accordance with that value of the discharge resistance of the fluorescent lamp (LL) which occurs at the lower limit of the range of dimming.

7. Electronic ballast according to Claim 1 or 2, characterized in that for the purpose of deriving the auxiliary controlled variable (HMG) derived from the



discharge resistance of the fluorescent lamp (LL), the auxiliary measuring circuit (Un, KE1, KE2) is supplied by a low-frequency AC voltage (Un), and comprises first coupling elements (KE1) for superimposing this low-frequency AC voltage with the high-frequency AC operating voltage of the fluorescent lamp and second coupling elements (KE2) for filtering out a corresponding low-frequency AC voltage signal, as well as a rectifier circuit (GL) for rectifying this filtered-out AC voltage signal, and the voltage divider (R2/R3) of the auxiliary measuring circuit, which outputs the auxiliary controlled variable at its centre tap, is connected to this rectifier circuit with its two resistors.

8. Electronic ballast according to Claim 7, characterized in that use is made as the low-frequency AC voltage of the AC supply voltage (Un), which is fed to the electrodes of the fluorescent lamp (LL) directly via the first coupling elements (KE1), in that the second coupling elements (KE2), which block both the high-frequency component of the AC operating voltage and a DC voltage component, are respectively connected to one of the electrodes of the fluorescent lamp, and in that a filter (SG) for smoothing the rectified low-frequency AC voltage signal is provided between the rectifier circuit (GL) and the voltage divider (R2/R3) of the auxiliary measuring circuit.

9. Electronic ballast according to one of the preceding claims, characterized in that at its output the auxiliary measuring circuit (Uzw, R1, R2, R3 or Un, KE1, KE2, R2, R3) has a threshold element (D1) which blocks this output until the auxiliary measured [sic] variable (HMG) derived from the discharge resistance of the fluorescent lamp (LL) overshoots a prescribed threshold value.