



Electronic ballast for at least one low-pressure
discharge lamp

5 The present invention relates to an electronic ballast
for the operation of at least one low-pressure
discharge lamp according to the preamble of claim 1.

10 Usually, nowadays ballasts are used that supply a high-
frequency alternating voltage to the gas discharge
lamps or fluorescent tubes. Apart from the voltage
supply, such electronic ballasts are used, moreover, to
preheat the electrodes of the gas discharge lamps and
to ignite and operate the lamps gently. With the aid
thereof, the degree of efficiency of the lamps is
15 increased, a longer service life is attained and
operation with reduced lamp output (dimming) is also
rendered possible.

20 In this connection, before the igniting voltage is
applied to the discharge lamp, the electrodes or the
coils of the lamp are as a rule preheated for a
specific period of time, thereby attaining a
comparatively gentle start of the lamp and thus a
longer service life of the lamp. Preheating is
25 effected with the aid of coil-heating that brings about
a flow of current through the two coils. In a ballast
that is known from EP 0 707 438 A3, for this a heating
transformer is used, the primary winding of which
transformer is connected to the output of an inverter
30 and which transformer has two secondary windings which
are each coupled to one of the two lamp coils. Before
the ignition of the discharge lamp, a frequency is set
for the alternating voltage supplied by the inverter,
which frequency is varied in relation to the resonant
35 frequency of the series resonant circuit in such a way
that the voltage that is applied to the discharge lamp

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does not, first of all, bring about any ignition of the lamp. Meanwhile, a substantially constant current flows through the two secondary heating circuits with the lamp coils, whereby the latter are preheated.

5 After a period of time that suffices for preheating, the frequency of the alternating voltage that is fed to the series resonant circuit is then shifted in the direction of the resonant frequency for so long until the thereby increasing voltage that is applied to the

10 discharge lamp brings about ignition of the lamp. According to EP 0 748 146 A1 or DE 295 14 817 U1, by opening a switch that is connected in series with the primary winding, the coil-heating can be switched off after the lamp has been ignited in order to reduce

15 power losses that would otherwise occur.

The demands on the electronic ballasts in this connection are becoming more and more extensive. Thus, for example, it is usual for a dimming operation to be

20 provided for the gas discharge lamp as well. Dimming that is effected to a great extent would, however, result in the lamp electrodes cooling below their emission temperature and thus in premature ageing of the lamp. In order to counteract this effect, the

25 electrodes of the gas discharge lamp also need to be heated to a certain degree during the operation in which ignition has already taken place. In particular, it is advantageous to set the heating of the electrodes as a function of the degree of dimming in such a way

30 that the latter are heated all the more, the greater the lamp is dimmed, that is, the darker it is. In accordance with EP 0 707 438 A3, the heating of the electrodes is regulated during the dimming in that the switch that is connected in series with the primary

35 winding is closed for a short time.

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The ballast should in addition also take on a monitoring function monitoring the state of the lamp in order to be able to detect possible operational disturbances and introduce appropriate measures. An operational disturbance can, for example, exist if one of the two coils or even both is or are defective or if the lamp has been completely removed. In the case of the electronic ballast described in EP 0 707 439 A3, the voltage drop across a resistor that is connected in series with the primary winding of the transformer and thus the heating current are measured in order to detect whether there is a coil-break or whether the lamp has been removed from the arrangement.

The method that has just been mentioned provides information on the state of the lamp, but not on what type of lamp it is. Often lamps do not differ externally, yet have differing electrical parameters and different power consumption. If a lamp whose performance features do not suit the electronic ballast is used in error, activation errors can result. In comparatively simple cases this impairs the illumination, but in more serious cases it can also result in damage to the lamp. Such problems could be avoided by detecting the type of lamp before ignition in a short check measurement and introducing appropriate measures. This can mean that the lamp is not preheated and ignited if it is the wrong type or better still that activation is effected that corresponds to the performance features of the lamp.

Basing considerations on the prior art mentioned above, it is therefore an object of the present invention to specify an electronic ballast for operating a low-pressure gas discharge lamp that performs the functions which have just been described, that is, lamp-

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identification, detection of the state of the lamp and coil-heating with controllable output, with the least possible outlay in terms of material and circuitry.

5 This object is achieved by means of a ballast which has the features of claim 1. An important feature of the ballast is an evaluating circuit arrangement which, for the purpose of identifying the type and the state of the lamp, detects and evaluates the current flowing
10 through the primary winding of the heating transformer and in addition also the current flowing through at least one of the two heating circuits. The type of lamp is then identified by measuring the current that flows by way of the lamp coil and which represents a
15 suitable measure of the coil resistance. The coil resistance in turn is a characteristic feature for distinguishing between lamps that have the same appearance, but different performance features. The current through the primary winding, on the other hand,
20 provides information on the state of the lamp. The transformer steps down the heating voltage at the primary winding towards the lamp to a great extent so that the levels of coil resistance, for their part, are stepped up towards the primary winding. The behaviour
25 of the transformer therefore depends greatly upon whether the coils are intact or whether, for example, a coil is defective and thus the pertinent secondary heating circuit is interrupted.

30 Furthermore, it is an object of the invention to render possible optimum control of the heating current and thus of the coil-heating. This is achieved in accordance with claims 5 and 23 in that the connection of the primary winding of the heating transformer to
35 the output of the inverter is regulated by a bidirectional switch consisting of two switches, with

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the primary winding of the heating transformer and a coupling capacitor being arranged between the two switches. The bidirectional switch can be formed by means of two field-effect transistors that are
5 connected in series and are orientated in opposition to each other and are preferably activated by means of a common pulse-width modulated signal, with the pulse duty factor of this signal determining the degree of heating. With the aid of this arrangement, temporary
10 discharge of a coupling capacitor contained in the heating circuit is avoided and thus a symmetrical heating voltage is attained.

Further developments of the invention constitute
15 subject matter of the subclaims. The resistance value of one of the two coils is used in order to determine the lamp type - as has already been mentioned. The latter is determined by way of the peak value of the so-called pin current. In order to identify a coil-
20 break or removal of the lamp, the current at the primary winding and at the same time as well the pin current are measured and both currents are set in relation to each other. This method makes it possible to make a statement on the state of the lamp
25 independently of possible voltage fluctuations. In this connection, it is preferably first examined whether an intact lamp is present and only subsequently is the lamp type determined. In order to increase the reliability of the determination of the lamp, the
30 measurement can be carried out twice, once before and once after the preheating of the lamp. The resistance values thereby measured can be compared with internally stored reference values and can then be associated with known lamp types. Furthermore, before the start of the
35 coil-preheating and the lamp-identification a short test can be carried out to determine whether the coils

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are also actually cold. In this way, misinterpretations in the identification of the lamp, which can occur after a short-term mains failure, can be avoided. The current-measurements are preferably effected in each case by measuring the voltage drops across two measuring resistors which are arranged in the heating circuit of the primary winding and in the secondary heating circuit of a lamp coil respectively.

10 In a further development of the invention, the electronic ballast is constructed in such a way that the coil-heating is activated and the frequency of the alternating voltage that is applied to the load circuit with the lamp is set as a function of the type of lamp
15 previously determined. In order to set the coil-heating as a function of the degree of dimming of the lamp, it can be established that the lowering of the lamp current brought about by the dimming of the lamp is to be substantially compensated for by the heating
20 current. The level of the rated value for the pin current, that is, for the sum of the lamp current and heating current, is, in this connection, determined by the electronic parameters of the lamp. Preferably as well after the ignition of the lamp, a check
25 measurement is carried out at regular intervals in order to identify a coil-break that might possibly have occurred or to identify removal of the lamp.

30 The invention shall be explained in greater detail in the following with reference to the enclosed drawing in which:

Figure 1 shows the exemplary embodiment of a circuit arrangement in accordance with the invention;

35 Figure 2 shows a timing diagram of the control signals

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and the pertinent states of the switches during the normal/dimming operation of the lamp;

5 Figure 3 shows a timing diagram of the control signals before the ignition of the lamp; and

Figure 4 shows a possible flow chart of the different operating phases of the lamp.

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In accordance with Figure 1, the inverter of the ballast is formed by a half-bridge consisting of two electronic switches S1 and S2 which are connected in series, with each switch consisting of an MOS field-effect transistor. The two switches S1 and S2 are
15 activated by way of two terminals A1 and A2 respectively that are connected to the gates of the transistors and which lead to a control/evaluating circuit arrangement which is not shown. The lower
20 output of the half-bridge is connected to ground, whilst the direct voltage U_{BUS} , which can be generated, for example, by shaping the usual mains voltage by means of a combination of radio-interference suppressors and rectifiers, is applied to its input.
25 As an alternative to this, however, any other direct-voltage source can also be applied to the input of the half-bridge.

The load circuit, which contains the discharge lamp LA,
30 is connected to the output of the half-bridge, that is, to the common nodal point of the two switches S1 and S2. Said load circuit consists of a series resonant circuit which is composed of an inductance coil L1 and a resonant capacitor C2. Furthermore, a coupling
35 capacitor C1 is arranged between the inductance coil L1 and the resonant capacitor C2. The upper cathode of

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the two cathodes of the low-pressure gas discharge lamp LA is connected to the connecting node between the two capacitors C1 and C2. The two cathodes of the lamp LA each have two terminals, provided between which there is a respective heating coil W1 and W2 for heating the cathodes. The lower cathode of the lamp LA is in turn connected to ground by way of two resistors R1 and R3 which are connected in series. The second terminal of the resonant capacitor C2 is likewise also connected to ground so that the lamp LA and the resonant capacitor C2 are connected in parallel with each other. The function of the second resistor R3 will be described further later.

For the purpose of heating the two coils W1 and W2, a heating transformer is provided that consists of a primary winding Tp and also of two secondary windings Ts1 and Ts2. The secondary windings Ts1 and Ts2 are each connected in a series circuit arrangement to a respective coil W1 and W2 of the lamp LA so that two separate secondary heating circuits are formed. The resistor R3 is arranged within the secondary heating circuit of the lower coil W1 so that both a lamp current flowing through the lamp LA and the heating current flowing through the lower coil W1 flow in the same direction through the measuring resistor R3. The primary winding Tp is a component part of a series circuit arrangement which additionally has a coupling capacitor C3 and two controllable switches S3 and S4 between which the primary winding Tp and the coupling capacitor C3 are arranged. At its lower end this series circuit arrangement is connected to ground by way of a further resistor R2 and at its upper end it is connected to the common nodal point of the two switches S1 and S2 of the half-bridge so that it is connected in parallel with the load circuit and the lower branch of

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the half-bridge. The two switches S3 and S4 also each consist of a field-effect transistor, yet - as can be inferred from Figure 1 - are orientated in opposition to each other so that a bidirectional switch is formed. Furthermore, the two free-wheeling diodes D3 and D4 of the two transistors S3 and S4 are shown in the circuit diagram.

The gates of the two switches S3 and S4 are activated by means of the control/evaluating circuit arrangement by means of a pulse-width modulated signal by way of the terminal A3. Located between the two gates, furthermore, there is a diode D1. The common nodal point between the output of the diode D1 and the gate terminal of the switch S3 is connected, by way of a capacitor C4 and a resistor R4 connected in parallel with this capacitor C4, to the common nodal point of the two switches S1 and S2 of the half-bridge. Finally, the circuit arrangement has three outputs A4, A5 and A6 that are connected to the control/evaluating circuit arrangement and which are used to measure the voltage drops across the resistors R2 and R3.

The measurement signals at the outputs A4, A5 and A6 are used to identify the type of lamp and to detect the state of the lamp, that is, to check whether it is intact or whether possibly one of the two coils is broken. On the other side, the control/evaluating circuit arrangement, by means of the clock signals at the terminals A1 and A2, regulates the alternating voltage, which is fed to the load circuit, and, by means of the pulse-width modulated signal at the terminal A3, regulates the heating of the coils W1 and W2.

In the following, firstly the function of the

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bidirectional switch formed from the two field-effect transistors S3 and S4 for heating the coils W1 and W2 and the activation of the lamp LA shall be explained in greater detail.

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Figure 2 shows a typical timing diagram of the control signals that are applied to the three inputs A1, A2 and A3 and also the resultant state of the four switches S1 to S4 for an operating state of the lamp LA in which ignition has already taken place and there is slight dimming. In this connection, regularly alternating signals are applied to the terminals A1 and A2 of the two half-bridge switches S1 and S2 between a high level H and a low level L in such a way that in each case one of the two switches S1 or S2 is opened (1) and the other is closed (0). At the centre point of the half-bridge in this way a high-frequency alternating voltage that has the period length τ_0 or the frequency $1/\tau_0$ is generated and fed to the load circuit. The degree of dimming of the gas discharge lamp is substantially determined by the deviation of the frequency $1/\tau_0$ of the alternating voltage from the resonant frequency of the load circuit. A large deviation in this connection signifies a high level of dimming.

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In the example shown in Figure 2 it may be assumed that the selected period length τ_0 actually gives rise to a certain dimming of the lamp. In order to counteract premature ageing of the lamp, the two electrodes must be heated by an additional heating current so that they continue to be kept at their emission temperature. The heating is effected by low-frequency connection of the primary heating circuit to the centre point of the half-bridge at regular intervals τ_H and for a predetermined period of time τ_{HH} . In these heating phases τ_{HH} the capacitor C3 then decouples the direct-

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voltage component so that a symmetrical square-wave voltage with a peak value of $U_{BUS}/2$ is produced in the primary winding T_p of the heating transformer. Even during a comparatively long off-phase τ_{HL} of the heating transformer, the coupling capacitor $C3$ should not be discharged so that a symmetrical voltage signal can be generated at the primary winding T_p at any time. This is important in particular in such cases in which a multi-lamp unit is formed, in which unit the peak value of the primary voltage need barely be applied to the transverse discharge voltage of the low-resistance coils. If the heating circuit were connected to the centre point of the half-bridge just with the aid of one single switch (for example just by means of the lower transistor $S4$), the coupling capacitor $C3$ would, however, be discharged by way of the internal free-wheeling diode $D4$ of this transistor during the periods in which the lower switch $S2$ of the half-bridge is closed.

In the present exemplary embodiment therefore a bidirectional switch is formed from the two field-effect transistors $S3$ and $S4$, with the gates of the two transistors $S3$ and $S4$ being activated by means of the common pulse-width modulated signal $A3$. The mode of functioning of this bidirectional switch can also be inferred from the curves in Figure 2. If the signal $A3$ has a low level L , both switches $S3$ and $S4$ are opened and the coil-heating is switched off. If the control signal $A3$ changes to a high level H at the beginning of a heating pulse τ_{HH} , the lower transistor switches through and switch $S4$ is thereby closed (1). However, as long as the upper switch $S1$ of the half-bridge is also closed (1), the transistor $S3$ still remains blocked and the second switch $S3$ is open (0). In this phase, current then flows by way of the internal free-

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wheeling diode D3 of this transistor S3, whereby the coupling capacitor C3 is charged. If the clock pulse of the half-bridge changes, that is, switch S1 closes (0) and switch S2 opens (1), the source potential of the transistor S3 connects to ground and the switch S3 also closes (1). The coupling capacitor C3 can then be discharged and supply its energy again.

In order to switch off the heating phase τ_{HH} , the PWM-signal A3 is switched to a low level and the transistor S4 is thereby blocked. The gate of the transistor S3 is also then no longer activated by way of the diode D1 and the transistor S3 is now kept blocked, in a passive manner, by way of the resistor R4. The additional capacitor C4 guarantees that the transistor S3 is not switched on unintentionally during the off-phase τ_{HL} on account of the Miller capacitance. During this period of time τ_{HL} , both switches S3 and S4 are consequently open and any discharge of the coupling capacitor C3 by way of one of the two free-wheeling diodes D3 or D4 is also precluded. In this way, consequently at regular intervals τ_H or with the frequency $1/\tau_H$ for a predetermined period of time τ_{HH} an alternating voltage with the frequency $1/\tau_0$ supplied by the inverter is generated in the primary winding T_p of the heating transformer and in the secondary heating circuits of the two lamp coils W1 and W2. The bidirectional switch is of course not restricted to use in the ballast that is described here, but can in principle be used in the case of a heating transformer and a coupling capacitor connected therewith, with a substantial improvement in the control of the heating current being attained thereby in each case.

The period length τ_H of the signal A3 is then substantially longer than the period length τ_0 of the

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high-frequency clock signals A1 and A2. The choice of the low frequency $1/\tau_H$ is dependent upon a plurality of considerations. On the one hand, not too high a frequency $1/\tau_H$ or not too short a period τ_H should be selected, since otherwise too coarse a gradation of the heat output results. Since the connection of the heating circuit has an effect upon the light output of the lamp, signs of flickering can then result. On the other hand, the selected frequency $1/\tau_H$ may not be too low either, since otherwise the two coils W1 and W2 cool too much during the off-phase τ_{HL} , something which can have a negative effect upon the service life of the lamp LA. The selected frequency $1/\tau_H$ of the pulse-width modulated signal A3 should therefore be such in each case that a substantially constant electrode temperature sets in.

The effective value of the heating voltage and thus the degree of the heat output are determined by the pulse duty factor of the pulse-width modulated signal A3 and by the relationship over time between the high phase τ_{HH} and the low phase τ_{HL} . Said value is preferably set in accordance with the degree of dimming and the type of lamp LA. The corresponding method for setting the heat output will be explained further below. If the lamp LA, which has already ignited, is operated close to the resonant frequency of the load circuit and thus with almost maximum output, the coil-heating can be switched off completely in order to reduce power losses. The service life of the lamp LA is not substantially impaired thereby, since the operating temperature of the electrodes is sufficient in this case. In contrast with this, during the preheating of the coils W1 and W2 a comparatively high heat output is selected in order to make it possible for there to be a short preheating time and rapid ignition of the lamp LA. During the

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preheating, the half-bridge is operated further at a very high frequency $1/\tau_0$ of almost 120kHz. Since this frequency lies well above the resonant frequency of the load circuit, premature and unintentional ignition is avoided.

The process of igniting the lamp LA is carried out in a known manner. If no malfunctions have been identified during the detection of the state of the lamp that is still to be explained in greater detail and during the identification of the lamp, at the end of a predetermined heating time the frequency of the alternating voltage supplied by the half-bridge is lowered and approximated to the resonant frequency of the load circuit. As a result, the voltage that is applied to the lamp LA is increased until ignition is finally effected.

A simple method for regulating the heat output as a function of the degree of dimming of the lamp LA, shall now be explained in brief. This method consists in controlling the current that flows off from the lower coil W1. This so-called pin current is composed of two components, on the one hand of the lamp current that flows by way of the ignited lamp LA and, on the other hand, of the mean heating current that is generated by the heating transformer. The aim now is to keep this pin current substantially at a predetermined rated value or within a predetermined range. If the lamp LA is namely dimmed by changing the alternating voltage frequency, the lamp current and the electrode temperature are reduced as a result. A measure for the additional heating of the electrodes can now be selected, for example, in such a way that the current reduction brought about by the dimming is to be compensated for again by the heating current. The

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control/evaluating circuit arrangement is therefore preferably formed in such a way that it measures the pin current and modulates the pulse width of the control signal at the terminal A3 in an appropriate manner. The current is thereby measured by briefly measuring the voltage drop across the measuring resistor R3 by means of a voltmeter (not shown) that is connected to the outputs A5 and A6 and which is a component part of the control/evaluating circuit arrangement or routes the measurement result on to the latter.

The value that is predetermined for the pin current is determined by *inter alia* the type and the power consumption of the lamp LA. In this connection, the electronic ballast is formed in such a way that it independently identifies the type of lamp with its specific electrical parameters (for example preheating current, lamp current, lamp output), and the activation of the lamp LA and the coil-heating by way of the signals A1, A2 and A3 is then effected in an appropriate manner. Since lamps that have different parameters externally often only differ very little or not at all, by means of automatic identification of the lamp at the same time as well it is possible to avoid activation errors that can result in unsatisfactory light efficiency or even in damage.

In the case of the ballast in accordance with the invention, the lamp is identified by measuring the resistance of one of the two coils. This coil resistance is a feature that suffices to distinguish between lamps which fit into a common socket, but have different performance parameters. With knowledge of the supply voltage that is fed to the inverter, the simplest possibility of determining the coil resistance

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consists in measuring the peak value of the pin current which, in the case of the circuit arrangement shown in Figure 1, is also detected by means of the voltage drop across the measuring resistor R3, by way of the outputs A5 and A6. The coil resistance is preferably measured at the beginning and at the end of the preheating phase. Since during the preheating - that is, before the lamp LA is ignited - lamp current does not yet flow, in this case it is also possible to measure the voltage drop between the terminal A6 and ground. During the identification of the lamp, a comparatively low heat output (approximately 5% pulse duty factor) is set in order to avoid excessive heating of the coils W1, W2. The half-bridge at this time runs at a high frequency of approximately 120kHz.

The pin current is preferably measured, and possibly averaged, in each case at the end of the switch-on phase of the upper switch S1 of the half-bridge. The peak values which are measured are then in each case compared with a stored reference value, and the type of lamp is ascertained with the aid of the result of the comparison. For each lamp type, consequently, two resistance reference values are required, one for the cold coils W1, W2 and one for the preheated coils W1, W2. It is to be noted in this connection that the pin current is not only dependent upon the coil resistance, but also upon the coil voltage and thus upon the bus voltage U_{BUS} that is fed to the inverter. In order to avoid possible fluctuations and measurement errors, the identification of the coil is therefore not carried out until after the system has settled and until after the bus voltage U_{BUS} has stabilized. As an alternative to this, however, the bus voltage U_{BUS} could be determined in a separate measurement and the voltage drop across the measuring resistor R3 could be set in relation

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thereto, for example by forming the differential voltage. In this way, it would even be possible to carry out the identification of the lamp independently of such fluctuations.

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A further misinterpretation in the determination of the lamp can occur if the mains voltage supplying the electronic ballast fails for a short time or is briefly switched off and back on. In each case, this is interpreted by a ballast as a restart of the lamp LA and consequently preheating and identification of the lamp are carried out one more time. However, the coils W1, W2 in this case are not yet cooled and accordingly have a different resistance. The identification of the lamp then leads to an incorrect result. In order to make allowances for this possibility, before the resistance is determined it is examined whether the coil W1, W2 is hot or cold. If the coil W1, W2 is actually still hot, the lamp LA is deliberately preheated with a somewhat lower heat output, and identification of the lamp is only carried out on the basis of the resistance measurement at the end of the preheating phase. The somewhat different form of preheating can be tolerated in this connection since this case only seldom occurs. The distinction between a hot and a cold coil W1, W2 is made by way of a measurement of the change in the coil resistance within a predetermined short time span of, for example, 10ms. If the change is negative, it is assumed that the coil W1, W2 is hot or warm and the preheating is carried out at a reduced level. If, on the other hand, no change can be ascertained, this is seen to indicate the presence of a cold coil W1, W2 and therefore the usual preheating and determination of the lamp are carried out. This check measurement is also carried out by means of two short scans of the pin current or of the

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to the terminal A3 and the coupling capacitor C3 is charged. As in the case of the identification of the lamp, this measurement is therefore also carried out shortly before the end of the switch-on phase of the upper switch S1 of the half-bridge.

If both coils W1 and W2 of the lamp LA are intact, the following relationship applies to the peak values of two measured currents:

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$$I_{R2} = I_{R3} \cdot n \cdot 1/\bar{u}$$

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$\bar{u}$ then denotes the transformation ratio and n the number of intact coils W1, W2. The transformation ratio $\bar{u}$ of the heating transformer follows from the maximum coil voltage. It should be ensured that this ratio $\bar{u}$ does not become too large, since otherwise the capacitive currents with preheating switched off give rise to excessive coil losses during the operation. In order to evaluate the state of the lamp, the primary current I_{R2} is then set in relation to the pin current divided by the transformation ratio $I_{R3} \cdot 1/\bar{u}$ and the result that theoretically produces the number of coils n is evaluated. In the simplest way, this is effected by comparing the result with a reference value. If, for example, a value that is smaller than 1.3 results, in all probability there is a coil-break. Since current still flows through the lower secondary heating circuit of the coil W1, accordingly the upper coil W2 must be defective. If, on the other hand, no current at all flows through the measuring resistor R3, either the lower coil W1 is defective or no lamp LA at all is present. In this way, it is consequently possible to detect the possible states of the lamp in a simple and rapid manner.

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A further advantage of this method can be seen in the fact that a statement on the state of the lamp is thereby obtained that is independent of possible fluctuations in the supply voltage U_{BUS} . Whilst a fluctuation in U_{BUS} affects the result of measurement of the pin current, the primary heating current is also changed likewise. It is not absolutely necessary to wait until after the system has settled and the supply voltage U_{BUS} has stabilized. Furthermore, the influence of possible coil resistance tolerances is also reduced. In the same way, during the normal operation of the lamp LA it is also possible to check the state of the lamp at regular intervals in order to detect a coil-break that occurs in the meantime. For this purpose, however, the lamp current should not affect the heating current too much, for example it should not amount to more than 10% of the pin current. If a coil-break occurs whilst the lamp is in operation or if the lamp is removed, this check measurement can be carried out repeatedly until an intact lamp is identified in the system again. A restart can then be initiated automatically.

A possible temporal sequence of these measurements which have just been described for the identification of the lamp and for the detection of the state of the lamp is shown in the timing diagram in Figure 3. The start of the lamp occurs at instant T_0 . It may be assumed here that at this instant T_0 the system has already settled and the supply voltage U_{BUS} has stabilized. Immediately after the start of the lamp, in the first place the check measurement is effected to determine whether an intact lamp is inserted or whether possibly there is a coil-break. Since here the pin current at the resistor R3 is compared with the primary current of the coil-heating at the resistor R2, this

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measurement must be carried out at an instant T_w at which the control signals at the terminals A1 and A3 lie at a high level H. As has already been said, all the measurements are preferably carried out shortly before the signals A1 and A2 change. Furthermore, a frequency of almost 120kHz is selected for these signals.

If an intact lamp has been identified, subsequently two measurements of the coil resistance are carried out shortly one after the other at the instants T_{L1} and $T_{L1'}$ in order to ascertain whether the coils W1, W2 are warm or cold. Since in this connection variations in temperature or changes in resistance are to be observed, during this time a low pulse duty factor is selected for the control signal at the terminal A3. The spacing between T_{L1} and $T_{L1'}$ amounts to approximately 10ms.

Subsequently, in the period of time τ_{VH} the coils W1, W2 are preheated, with the heat output occurring in accordance with the state of the coils W1, W2, that is, for example a higher heat output is set if the resistance measured at the later instant $T_{L1'}$ is not lower than the resistance value measured at the instant T_{L1} . After the preheating time, at the instant T_{L2} the coil resistance is measured again and then with the aid of the measurement results at the time T_{L1} , $T_{L1'}$, and T_{L2} the type of lamp is determined. If the coils W1, W2 were warm, only the result of the third measurement is taken into consideration; if the coils were cold, all three measurements can be used for the determination of the lamp. Subsequently, the ignition of the lamp LA, which is not further represented, is initiated.

A summary of the functions of the electronic ballast in

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accordance with the invention that have been outlined is presented in Figure 4. This shows a simplified flow chart of the individual phases during the operation of the lamp. After switching on the mains voltage or a short mains failure 100, in the first place in the manner that has just been described the query 101 is put in order to determine whether there is a coil-break. If this is the case or if there is no lamp at all in the system, the query 101 is repeated continuously until finally an intact lamp is identified.

If an intact lamp has been identified, in the next step 102 it is checked, by means of the two pin-current measurements carried out shortly one after the other, whether the coils are cold. If the coils are actually cold, the lamp is preheated in the normal manner and the identification of the lamp is carried out on the basis of the measurement results before and after the preheating phase 103. If a warm coil has been identified instead, only a reduced level of preheating 104 is carried out and the type of lamp is determined at the end. After preheating 103 or 104 respectively, finally the lamp is ignited 105, with the four switches being activated as a function of the lamp type that has been identified.

After the ignition 105, the system operates in normal or dimmed operation 106, as an alternating-voltage frequency, corresponding to the type of lamp and the desired degree of dimming, and heat output are set by the control/evaluating circuit arrangement. During this phase, in addition at regular intervals once more a query 107 is put to determine whether a coil-break has possibly occurred or whether the lamp has been removed. If this is the case, the normal/dimming

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operation is brought to an end and the system is reset to the state of the original coil-break query 101. It would, however, also be conceivable to switch off the inverter upon identification of a coil-break or another defect of the lamp. It would then be possible to monitor, with the aid of a suitable circuit arrangement, whether the defective lamp has been replaced by a new one. If, finally, an intact lamp is identified in the system again, a restart can be initiated automatically. If no change in the state of the lamp is ascertained in the check measurement 107, the lamp is activated for so long in normal/dimming operation until it is finally switched off. In this connection, the flow chart in Figure 4 only shows one possibility of the sequence of the various check measurements and phases of the lamp. Of course, very many other control methods in which the various measurements take place at different instants, would also be possible.

Consequently, all in all in order to control the lamp in the manner that has just been described, current measurements at two different points in the circuit arrangement (in one of the two secondary coil-heating circuits and in the primary heating circuit) as well as a controllable switch arrangement for the connection of the primary heating circuit are required. The material outlay for such an extension is then comparatively small. It follows from the descriptions of the various detection measurements that, instead of the voltage measurements at the two measuring resistors R2 and R3, other current-measuring methods can also be used, since for the purposes of lamp-identification and detection of a coil-break only the respective current intensities need to be determined. Moreover, the arrangements that are shown for the measuring resistors R2 and R3 are not

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prescribed absolutely. For example, the measuring resistor R2 can also be located between the two switches S3 and S4. It is also possible to measure the pin current as well in the heating circuit of the upper
5 coil W2 and thus measure the coil resistance of the upper coil W2.

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Claims

1. Electronic ballast for at least one low-pressure discharge lamp (LA), having an inverter that is fed
5 with direct voltage (U_{BUS}) and the output of which is connected to a load circuit containing terminal contacts for the lamp (LA), having a heating transformer that has a primary winding (T_p), which is connected to the output of the inverter, and a
10 respective secondary winding (T_{s1} , T_{s2}), which is located in a heating circuit with a coil ($W1$, $W2$), for heating each of the two electrodes of the lamp (LA), having a series circuit arrangement that is connected in parallel with the load circuit and which contains
15 the primary winding (T_p) of the heating transformer and an electronic switch arrangement ($S3$, $S4$), and having an evaluating circuit arrangement that measures the current flowing through the series circuit arrangement with the primary winding (T_p) and the electronic switch arrangement ($S3$, $S4$), **characterised in that** the
20 evaluating circuit arrangement additionally also measures the current flowing through at least one of the two heating circuits and evaluates the amplitudes or the time characteristic of the two measured currents
25 in order to identify the type of lamp and the state of the lamp.

2. Electronic ballast according to claim 1,
characterised in that for the purpose of measuring the
30 current through the series circuit arrangement with the primary winding (T_p) and the electronic switch arrangement ($S3$, $S4$), connected in series with the latter there is a first measuring resistor ($R2$), and in that the evaluating circuit arrangement evaluates the
35 voltage which is generated at the first measuring resistor ($R2$) by the current (I_{R2}) which flows through

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the latter.

3. Electronic ballast according to claim 1 or 2,
characterised in that for the purpose of measuring the
5 current through one of the two heating circuits this
heating circuit contains a second measuring resistor
(R3), and in that the voltage that drops across this
second measuring resistor (R3) and which is generated
by the current (I_{R3}) flowing through the latter is fed
10 to the evaluating circuit arrangement.

4. Electronic ballast according to claim 3,
characterised in that the second measuring resistor
(R3) is arranged in one of the two heating circuits in
15 such a way that a lamp current flowing through the lamp
(LA) after the lamp (LA) has been ignited flows in the
same direction in which a heating current that is
generated by the heating transformer flows through the
second measuring resistor (R3).

20 5. Electronic ballast according to one of claims 1 to
4, **characterised in that** the electronic switch
arrangement (S3, S4) is formed by two field-effect
transistors (S3, S4) which are orientated in opposition
25 to each other, and in that the primary winding (Tp) of
the heating transformer and also a coupling capacitor
(C3), which is connected in series with the latter, are
arranged between the two field-effect transistors (S3,
S4).

30 6. Electronic ballast according to claim 5,
characterised in that the gates of the two field-effect
transistors (S3, S4) are activated by way of a common
pulse-width modulated signal (A3).

35 7. Electronic ballast according to claim 4 and claim

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6, **characterised in that** after the lamp (LA) has been ignited a pulse duty factor is set for the pulse-width modulated signal (A3) in such a way that the current (I_{R3}) flowing through the second measuring resistor (R3) is substantially equal to a rated value.

8. Electronic ballast according to claim 7, **characterised in that** the rated value is established by the type of lamp detected by the evaluating circuit arrangement.

9. Electronic ballast according to one of claims 1 to 8, **characterised in that** the inverter contains a half-bridge consisting of two electronic switches (S1, S2) that are connected in series and which are alternately opened and closed, and in that the load circuit, which contains the lamp (LA), and the series circuit arrangement with the primary winding (T_p) and the electronic switch arrangement (S3, S4) are connected in parallel with one of the two electronic switches (S1, S2).

10. Electronic ballast according to claim 9 and one of claims 5 to 8, **characterised in that** a diode (D1) is arranged between the two gates of the field-effect transistors (S3, S4), and in that the gate of one of the two field-effect transistors (S3, S4) is connected to the output of the inverter by way of a resistor (R4).

11. Electronic ballast according to claim 10, **characterised in that** a further capacitor (C4) is connected in parallel with the resistor (R4).

12. Electronic ballast according to one of the preceding claims, **characterised in that** it contains a

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rectifier that is connected to the mains and which generates the direct voltage (U_{BUS}) that is to be fed to the inverter.

5 13. Electronic ballast according to one of the preceding claims, **characterised in that** the load circuit contains an inductance coil (L1) which is connected in series with the lamp (LA), and a resonant capacitor (C2) which is connected in parallel with the
10 lamp (LA).

14. Electronic ballast according to one of the preceding claims, **characterised in that** for the purpose of identifying the type of the lamp (LA) the current
15 (I_{R3}) that flows through one of the two heating circuits and which is dependent upon the respective coil resistance is measured and evaluated by the evaluating circuit arrangement.

20 15. Electronic ballast according to claim 14, **characterised in that** for the purpose of identifying the type of the lamp (LA) the evaluating circuit arrangement compares the peak value of the current (I_{R3}), measured in one of the two heating circuits, with
25 reference values.

16. Electronic ballast according to claim 14 or 15, **characterised in that** measurements for the purpose of identifying the lamp type are carried out in each case
30 at the beginning and at the end of a preheating phase of the lamp (LA).

17. Electronic ballast according to claim 16, **characterised in that** in a check measurement for
35 distinguishing between a warm and a cold coil (W1, W2) before the preheating phase of the lamp (LA) the

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evaluating circuit arrangement compares the amplitudes or the peak values of two currents (I_{R3}), measured shortly one after the other, through one of the two heating circuits.

5

18. Electronic ballast according to claim 16 and 17, **characterised in that** only the result of the measurement at the end of the preheating phase of the lamp (LA) is used in order to identify the type of lamp if a warm coil (W1, W2) has been identified in the check measurement.

10

19. Electronic ballast according to one of the preceding claims, **characterised in that** for the purpose of identifying a change of lamp or lamp defect the evaluating circuit arrangement evaluates simultaneously measured peak values of the currents (I_{R2} , I_{R3}) through the series circuit arrangement with the primary winding (Tp) and the electronic switch arrangement (S3, S4) and also through one of the two heating circuits.

15

20

20. Electronic ballast according to claim 19, **characterised in that** the evaluating circuit arrangement sets the simultaneously measured peak values in relation to each other and evaluates the result.

25

21. Electronic ballast according to claim 19 or 20, **characterised in that** a measurement is effected in order to identify a change of lamp or lamp defect immediately after the ballast has been switched on.

30

22. Electronic ballast according to one of claims 19 to 21, **characterised in that** after the lamp (LA) has been ignited a measurement is carried out at regular intervals to identify a change of lamp or lamp defect.

35

23. Electronic ballast for a low-pressure discharge lamp (LA), having an inverter that is fed with direct voltage (U_{BUS}) and the output of which is connected to a load circuit containing terminal contacts for the lamp (LA), having a heating transformer that has a primary winding (T_p), which is connected to the output of the inverter, and a respective secondary winding (T_{s1} , T_{s2}), which is located in a heating circuit with a coil ($W1$, $W2$), for heating each of the two electrodes of the lamp (LA), and having a series circuit arrangement that is connected in parallel with the load circuit and which contains the primary winding (T_p) of the heating transformer and a first switch ($S4$), **characterised in that** the series circuit arrangement with the primary winding (T_p) and the first switch ($S3$) additionally contains a coupling capacitor ($C3$) and a second switch ($S4$), with the primary winding (T_p) and the coupling capacitor ($C3$) being arranged between the two switches ($S3$, $S4$).

20

24. Electronic ballast according to claim 23, **characterised in that** the two switches ($S3$, $S4$) are formed by two field-effect transistors ($S3$, $S4$) which are orientated in opposition to each other.