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(54) **Method and apparatus for supplying high frequency alternating current to a low pressure discharge lamp**

(57) The lamp drive current is passed from the common point (V_{in}) of the switches (1,2) of a half-bridge inverter to a lamp load circuit formed by an inductor (L) connected in series with the lamp (4) and a DC blocking capacitor (5). A second capacitor (C) is connected in parallel with the series connection of the lamp (4) and the DC blocking capacitor (5). During normal operation of the lamp, the operating frequency of the half-bridge inverter (1,2) is kept with the help of control means (3) at the resonant frequency of the oscillatory circuit

formed by inductor (L) and second capacitor (C). The values of inductor (L) and second capacitor (C) are selected so that, at the resonant frequency of the same, there is obtained a desired lamp drive current (nominal operating current of the lamp) at a level which is substantially independent from the resistance (R) of lamp (4). Thus, the ballast circuit operates as a kind of constant-current generator allowing one and a single ballast to be used for a family of lamps with different power ratings.

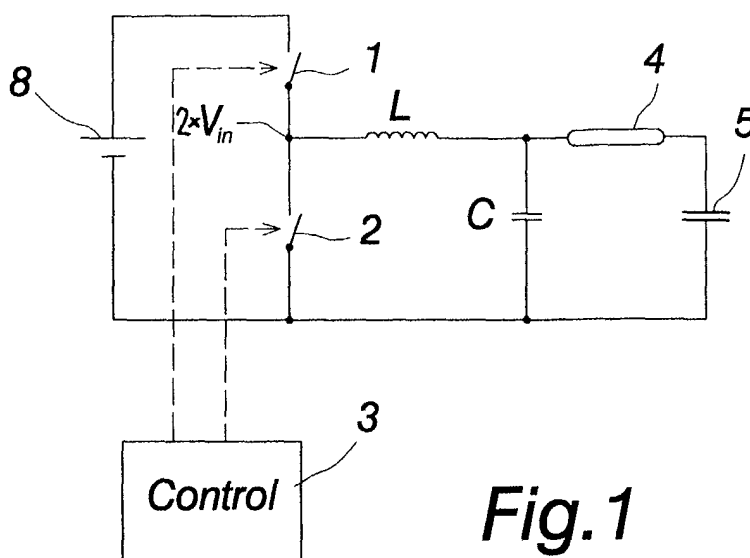


Fig. 1

Description

[0001] The present invention relates to a method for supplying high-frequency alternating current to a low-pressure discharge lamp, in which method the lamp drive current is passed from the common point of the switches of a totem-pole half-bridge inverter via an inductor connected in series with the lamp to a capacitor having so large a capacitance that permits the capacitor to act at DC voltage essentially as a power source.

[0002] The invention also relates to an electronic ballast for supplying high-frequency alternating current to a low-pressure discharge lamp, the ballast comprising a totem-pole half-bridge inverter and a lamp circuit connected to the common point of the inverter switches, the lamp circuit being comprised of a series configuration formed by an inductor, the lamp and a capacitor, the latter having such a large capacity that permits the same to act at DC voltage essentially as a power source, and of a second capacitor connected in parallel with the series connection of the lamp and the DC blocking capacitor.

[0003] In this type of conventional electronic ballast, the resonant frequency of the inductor with the second capacitor is utilized for heating the lamp cathodes prior to the ignition of the lamp. As soon as the lamp current begins to run, the inverter frequency is generally offset from the resonance, typically toward a lower frequency, in order to allow the inductor to pass a sufficiently large lamp drive current. Additionally, the frequency control has been utilized to realize a lamp intensity control facility.

[0004] The components and operating frequency of such conventional ballasts must be separately dimensioned and adapted for different lamp types operating at different input power levels. Recently, a family of four new lamp types has been released to the market with the same nominal current (170 mA) but having different nominal power ratings (14 W, 21 W, 28 W and 35 W).

[0005] It is an object of the invention to provide a method and ballast of the above-described type with such properties that allow one and the same ballast to be used in conjunction with all mentioned different lamp variants that operate essentially at the same nominal current but have different power ratings.

[0006] The above-stated goal is achieved by means of the method specified in appended claim 1. The goal is also realized by means of the ballast specified in appended claim 4. Details of preferred embodiments of the invention are disclosed in the dependent claims.

[0007] In the following, the invention will be examined in greater detail with the help of exemplary embodiments and a theoretical treatise by making reference to the appended drawings in which

FIG. 1 shows a simplified circuit diagram elucidating a ballast according to the invention as to its basic components only that are essential to

the function of the circuit in its different embodiments, whereby it is obvious to a person versed in the art that such a circuit incorporates a relatively large number of other components and auxiliary circuits essential to the function of the circuit but nonessential in the context of the present topic;

FIG. 2 shows the circuit diagram of FIG. 1 complemented with operation monitoring based on current/voltage sense signals 6, 7;

FIG. 3 shows a simplified model of the lamp circuit for theoretical treatise later in the text;

FIG. 4 shows a plot of the lamp voltage, current and power as a function of lamp drive frequency assuming the lamp resistance to be 485 ohm; and

FIG. 5 shows a plot of lamp current values for a given family of discharge lamps computed for the load resistance at the operating point of the lamps when the circuit inductance is 3.887 mH, capacitance of the resonant capacitor is 3.3 nF and input voltage is 410 V.

[0008] A ballast shown in FIGS. 1 and 2 comprises a half-bridge inverter 1, 2, as well as a lamp circuit connected to the common point V_{in} of the inverter switches 1, 2 and being comprised of a series configuration formed by an inductor L, a lamp 4 and a capacitor 5, the latter having such a large capacitance that permits the same to act at DC voltage essentially as a power source. A second capacitor C is connected in parallel with the series connection of the lamp 4 and the DC blocking capacitor 5. Reference numeral 8 denotes a DC source feeding the ballast circuit at 410 VDC, for instance.

[0009] During normal operation of lamp 4 with the lamp current passing through the discharge channel, the operating frequency of the half-bridge inverter 1, 2 is controlled with the help of an oscillator incorporated in control means 3 to stay tuned to the resonant frequency of the oscillatory circuit formed by inductor L and second capacitor C. To this end, inductor L and second capacitor C are dimensioned so that at the resonant frequency of resonant circuit components L, C, the inverter delivers the desired lamp current (e.g., 170 mA) at a constant level that is substantially independent of the resistance (denoted by resistance R in FIG. 3) of lamp 4. Simply, the circuit practically functions as a constant-current generator, whose output current is not dependent on the resistance R of load 4. Since this matter is by no means obvious and can be realized only at a predetermined resonant frequency for a predetermined inverter output current, the behavior of a resonant circuit delivering a constant current needs a theoretical treatise given below.

[0010] The following mathematical modeling concerns the simplified lamp circuit shown in FIG. 3. To eliminate all irrelevant details, only the four components shown in the equivalent circuit diagram are discussed in the elucidation of the theoretical background of the invention. In the diagram, V_{in} denotes the average common-point voltage of the totem-pole half-bridge. Since a sinusoidal voltage is easiest to deal with mathematically, the formulas are written for the first harmonic of the common-point voltage waveform only. Typically, the peak-to-peak output voltage of the ballast inverter in the applicant's ballast constructions is about 410 V. As the effective value of the first harmonic in a square wave is 0.9 times the peak value, the sinusoidal input voltage V_{in} of the circuit may thus be assumed to constant at 0.9·205 Vrms (= 184.5 Vrms). However, the peak value of the input voltage V_{in} to the circuit is only half of the peak output voltage $2 \times V_{in}$ of the ballast inverter inasmuch DC blocking capacitor 5 is omitted from the equivalent circuit. This is permissible because the role of the DC blocking capacitor in the present treatise is relatively insignificant. In FIG. 3, the lamp circuit inductor is denoted by reference letter L, while reference letter C denotes the starting capacitor. Resistor R denotes the resistance of the lamp at its operating point. Obviously, an actual lamp is rather nonlinear, but for a quick analysis it is permissible to assume the lamp to behave like a simple resistor. The effect of other resistive lamp elements such as the cathodes on the validity of the treatise is minor. Anyhow, it is a general goal of ballast design to minimize all losses.

[0011] In Eq. 1 is given the ratio of the voltage V_L over the resonant circuit resistance R to the input voltage V_{in} , while Eq. 2 respectively gives the ratio of the current I_L through the lamp resistance to the input voltage V_{in} . Both of these equations are written using the Laplace transform which is a common tool in circuit analysis.

$$\frac{V_L(s)}{V_{in}(s)} = \frac{R}{s^2 LRC + sL + R} \quad (1)$$

$$\frac{I_L(s)}{V_{in}(s)} = \frac{1}{s^2 LRC + sL + R} \quad (2)$$

[0012] Taking, e.g., a T5 14 W lamp as an example, it may be assumed on the basis of practical experience that the lamp inductor can be approximated with an inductance of 4 mH and the starting capacitor with a capacitance of 2.2 nF. To automate the mathematical computations of this modeling for the nominal load resistance, MathCad was used for plotting the curves shown in FIG. 4 for the lamp current and voltage, as well as for the lamp power. The nominal values are drawn by solid horizontal lines in the graphs. According to this example, a suitable lamp drive frequency appears to be in the range of approx. 40 kHz to 50 kHz.

[0013] In fact, Eq. 2 makes it possible to find such circuit parameters that make the lamp drive current independent from the load resistance (which in the equivalent circuit is resistance R that represents the lamp). The equation can be converted to the real plane, because it is sufficient to analyze the real component of current only, whereby

$$\frac{I_L}{V_{in}} = \frac{1}{\sqrt{L^2 C^2 R^2 \omega^4 + (L^2 - 2LCR)\omega^2 + R^2}} \quad (3)$$

[0014] In Eq. 3 above, ω is angular frequency.

[0015] To make this equation independent of the value of the load resistance, the sum of the terms containing parameter R in the square root part of the equation denominator must be zero:

$$L^2 C^2 \omega^4 - 2LC\omega^2 + 1 = 0 \quad (4)$$

[0016] From Eq. 4 it is simple to see that the lamp drive frequency must be equal to the resonant frequency of the oscillatory circuit formed by the lamp inductor and starting capacitor (Eq. 5).

$$\omega = \frac{1}{\sqrt{LC}} \quad (5)$$

[0017] As now the sum of terms containing R in Eq. 3 is 0, the equation simplifies to:

$$\frac{I_L(s)}{V_{in}(s)} = \frac{1}{L\omega} \quad (6)$$

[0018] From the above equations it is finally possible to solve Eqs. 7 and 8 that give the desired parameter values for the lamp inductor and starting capacitor:

$$L = \frac{V_{in}}{I_L \cdot 2\pi f} \quad (7)$$

$$C = \frac{I_L}{V_{in} \cdot 2\pi f} \quad (8)$$

[0019] Starting from a 48 kHz lamp drive frequency as a practical design value, Eqs. 7 and 8 solve as 3.05 nF for the starting capacitor and 3.6 mH for the lamp inductor. Since the capacitance value is rather non-standard, the equations are solved the other way around by asking: what frequency and inductance values allow the use of standard 3.3 nF capacitor. As a result, the proper frequency appears to be 44.4 kHz and the induc-

tor must be 3.887 mH. In FIG. 5 is plotted a family of curves representing the lamp drive current as a function of frequency at different lamp resistances. It can be seen that the curves meet each other at the desired lamp current of 170 mA.

[0020] As the above mathematical modeling was carried out for the first harmonic component of the input voltage only, the validity of the result was verified using a MicroCap circuit simulator, whereby a lamp drive current of 174 mA was obtained for the lamp resistance of each lamp size.

[0021] In FIG. 2 is additionally shown that the control means 3 include current sensing means 6, 3 for measuring the current passing through switch 2 of the half-bridge inverter. Based on these, the control means 3 can elevate the operating frequency of the half-bridge inverter 1, 2 substantially above the resonant frequency of the circuit formed by components L, C in the case that the sensed current, particularly the peak value thereof, tends to exceed or fall below the predetermined limit values. This precaution serves e.g., to prevent the voltage and current of the resonant circuit L, C from growing excessively high after lamp 4 is ignited. Reference numeral 7 denotes a facility of measuring the phase shift between the lamp circuit current and voltage. Such a measurement gives an option to verify that the lamp circuit is operating at its resonant frequency. With the provision that the measurement facility 7 is made available, it can be utilized, in addition to monitoring circuit operation at the constant resonant frequency programmed in the control means 3, as an alternative method for determining the operating frequency, whereby control means 3 need not have to be preprogrammed for a constant resonant frequency.

[0022] An additional benefit of the invention is that present ballast is also suited for use in two-lamp configurations where the power ratings of lamps adapted in a single lighting fixture may be different from each other (e.g., one 14 W lamp and one 35 W lamp in combination). Hereby, a greater freedom is gained in the design of illumination distribution.

Claims

1. A method for supplying high-frequency alternating current to a low-pressure discharge lamp (4), in which method the lamp drive current is passed from the common point (V_{in}) of the switches (1, 2) of a half-bridge inverter via an inductor (L) connected in series with the lamp (4) to a capacitor (5) having so large a capacitance that permits the capacitor to act at DC voltage essentially as a power source, **characterized in that**, during normal operation of the lamp (4), the operating frequency of the half-bridge inverter (1, 2) is kept at the resonant frequency of the series-connected circuit formed by said inductor (L) and a second capacitor (C) connected in parallel

with the series connection of the lamp (4) and the DC blocking capacitor (5), and that said resonant-circuit components (L, C) are selected so that, at the resonant frequency of the same, there is obtained a desired lamp drive current (I_L) at a level which is substantially independent from the resistance (R) of the lamp (4).

2. The method of claim 1, **characterized in that** the current passing through switch (2) of the half-bridge inverter is sensed and the operating frequency of the half-bridge inverter (1, 2) is elevated substantially above said resonant frequency in the case that the sensed current tends to exceed or fall below predetermined limit values.

3. The method of claim 1 or 2, **characterized in that** the operating frequency of the half-bridge inverter (1, 2) is kept at about 44.4 kHz when the capacitance of the capacitor (C) is about 3.3 nF and the inductance of the inductor (L) is about 3.89 mH.

4. An electronic ballast for supplying high-frequency alternating current to a low-pressure discharge lamp (4), the ballast comprising a half-bridge inverter (1, 2) and a lamp circuit connected to the common point (V_{in}) of the inverter switches (1, 2), the lamp circuit being comprised of a series configuration formed by an inductor (L), the lamp (4) and a capacitor (5), the latter having such a large capacity that permits the same to act at DC voltage essentially as a power source, and of a second capacitor (C) connected in parallel with the series connection of the lamp (4) and the DC blocking capacitor (5), **characterized in that**, during normal operation of the lamp, the operating frequency of the half-bridge inverter (1, 2) is kept at the resonant frequency of the series-connected circuit formed by said inductor (L) and second capacitor (C) and that said resonant-circuit components (L, C) are selected so that, at the resonant frequency of the same, there is obtained a desired lamp drive current at a level which is substantially independent from the resistance (R) of the lamp (4).

5. The electronic ballast of claim 4, **characterized in that** the capacitance of capacitor (C) is about 3.3 nF and the inductance of inductor (L) is about 3.89 mH and the operating frequency of the half-bridge inverter (1, 2) is about 44.4 kHz.

6. The electronic ballast of claim 4 or 5, **characterized in that** the control means (3) thereof includes measurement means (6, 3) for sensing the current passing through switch (2) of half-bridge inverter (1, 2) and that control means (3) are adapted to elevate the operating frequency of half-bridge inverter (1, 2) substantially above said resonant frequency in

the case that the sensed current tends to exceed or fall below predetermined limit values.

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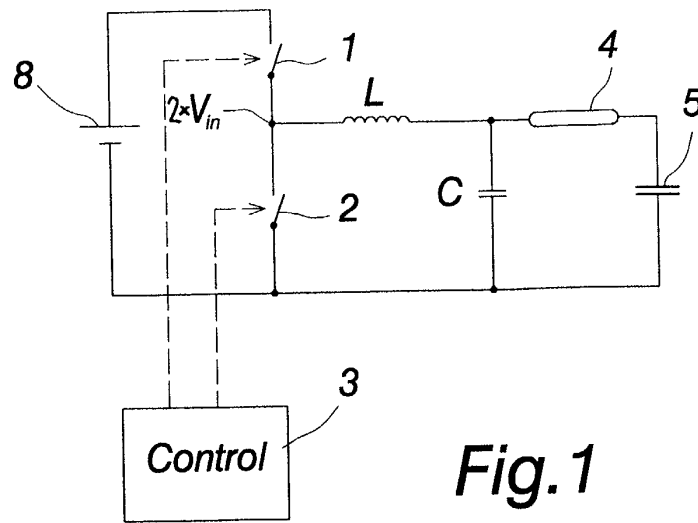


Fig.1

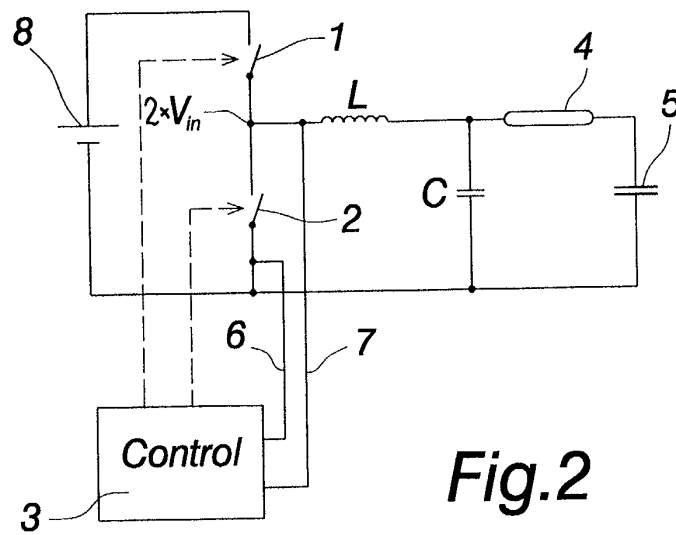


Fig.2

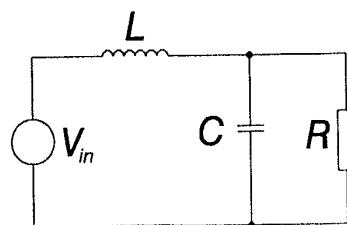


Fig.3

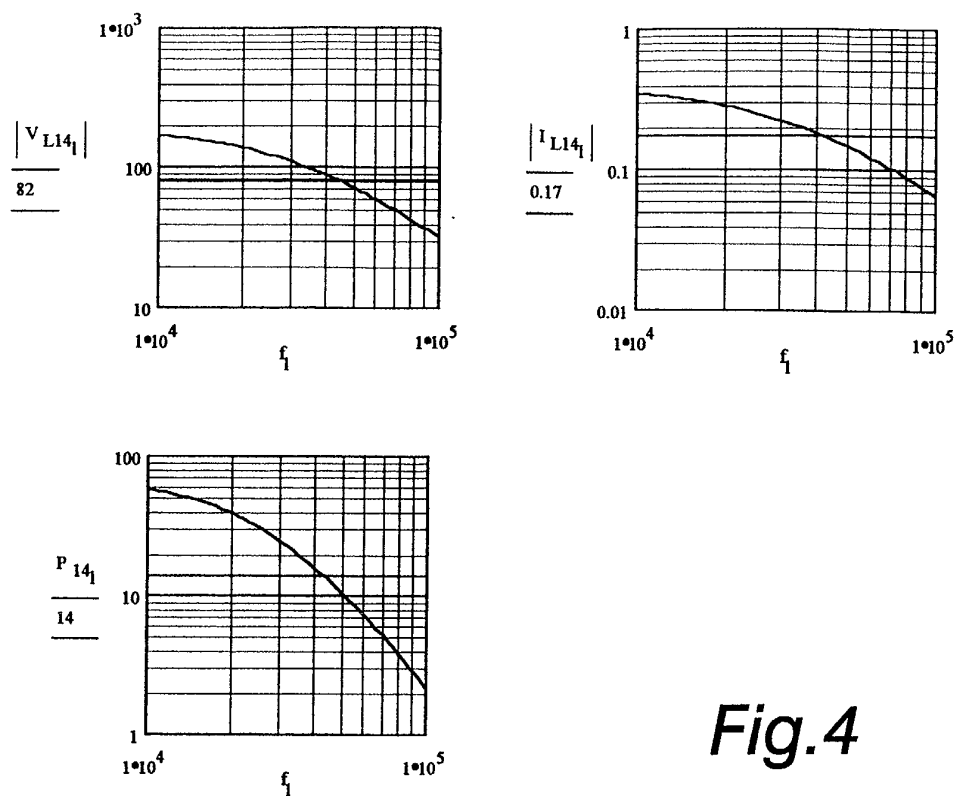


Fig.4

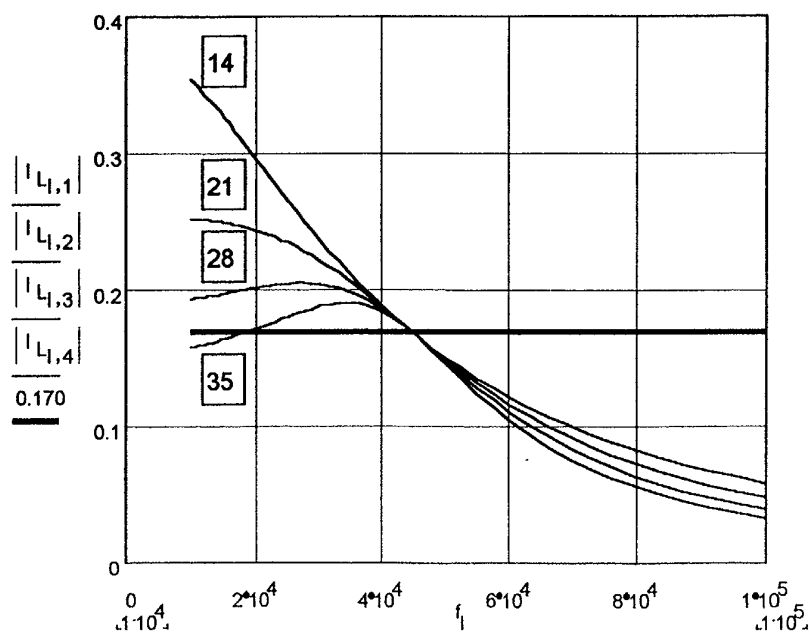


Fig.5