

DESCRIPTION

ELECTRONIC BALLAST, LIGHTING DEVICE HAVING THE ELECTRONIC BALLAST, AND LIGHTING SYSTEM WITH THE LIGHTING DEVICE TECHNICAL FIELD

The present invention is directed to an electronic ballast using an inverter to operate one or more discharge lamps, a lighting device and a lighting system using the same.

BACKGROUND ART

Generally, an electronic ballast for a discharge lamp includes a chopper for power converting a DC voltage rectified from a commercial power source, and an inverter which receives an output power from the chopper to supply a high frequency power to the discharge lamp. The ballast is configured to regulate the output power from the chopper in response to varying power requirement on the side of the discharge lamp, i.e., vary a switching frequency of a switching element constituting the chopper so as to regulate the output power of the chopper in match with the discharge lamps of different power requirements.

However, in a circumstance where power requirement of the discharge lamp will vary to a greater extent, for instance, where there is seen a considerable load power difference between conditions of operating a single discharge lamp and a plurality of discharge lamps, it becomes necessary to change an inductor constituting the chopper in accordance with the power requirement. For instance, as shown in FIG. 2, when operating the two discharge lamps of 45 W rated power, the operating frequency of the switching element of the chopper sees a maximum difference of about twice that for operating a single discharge lamp at respective source voltages. Under such

circumstance, due to a restriction on the chopper in regulating its output power, it is likely that the operating frequency of driving the chopper's switching element or an ON-period of the switching element goes out of a controllable range given by an integrated control circuit of the chopper. For example, when the discharge lamp requires a less power, the operating frequency of the chopper's switching element becomes considerably high, resulting in an excessively high chopper output voltage. In order to avoid this problem, it may be thought effective to use the inductor of great inductance for the chopper to keep the operating frequency within a low range. However, as the load power increases, such scheme will suffer from a shortage of the chopper output power even by increasing the ON-period of the switching element, thereby making it difficult to provide the power required by the inverter. Consequently, the single ballast is practically impossible for selectively operating the single discharge lamp and the multiplicity of the lamps. This poses a problem that individual designs are necessary to make individual choppers in accordance with the power requirement on the side of the discharge lamp or lamps, and further with the use of inductors of different inductance.

DISCLOSURE OF THE INVENTION

In view of the above problem, the present invention has been accomplished to provide an electronic ballast of a single circuit design which covers a situation where there is a large load power variation from a single-lamp operation to a multiple-lamp operation.

The electronic ballast in accordance with the present invention is configured to operate at least one discharge lamp, and includes a rectifier for rectifying an AC voltage to give a DC voltage, a chopper including an inductor, a

capacitor and a switching element which is controlled to repetitively interrupt the DC voltage from the rectifier through said inductor to develop a constant DC voltage across the capacitor, an inverter including at least one switching element which is controlled to turn and off at a suitable switching frequency so as to convert the DC voltage from the chopper into a high frequency AC voltage, and a resonant circuit including an inductor and a first capacitor and being configured to resonate the high frequency AC voltage to develop a resonated AC voltage to be applied to at least one discharge lamp for operating thereof.

The feature of the electronic ballast resides to include a power adjustor configured to designate a target power in match with a power requirement determined by the at least one discharge lamp, and an inverter controller configured to monitor a resonant index indicative of a resonant current flowing into the resonant circuit and to vary the switching frequency of said inverter in a feedback manner based upon the resonant index for keeping an output power applied to at least one discharge lamp at the target power.

With this arrangement, the electronic ballast of the present invention makes the feedback control based upon the resonant current through the resonant circuit for regulating the output voltage fed to the discharge lamp, and keeping the output power in match with the power requirement on the side of the load. Thus, there is no need to regulate the output voltage from the chopper, which enabling the single lamp operation as well as the multiple-lamp operation with the electronic ballast of an identical circuit design.

The electronic ballast of the present invention may include a temperature sensor configured to detect an environmental temperature. In this instance, the inverter controller is preferably configured to vary the switching frequency also

based upon the environmental temperature for keeping the output power applied to at least one discharge lamp at the target power. In view of that the discharge lamp requires a power which varies with the environmental temperature, more stable lamp operation is assured by regulation of the output power depending upon the environmental temperature.

Preferably, the resonant circuit includes a first resonant circuit composed of the inductor and the first capacitor connected in series across an output of said inverter, and a second resonant circuit composed of a second capacitor connected in series with at least one discharge lamp across the first capacitor. With the use of thus configured resonant circuit, it is possible to make a consistent control of the output power in match with the load for assuring more stable discharge lamp operation.

Further, the inverter controller may be configured to vary the switching frequency within a predetermined range which varies with the power requirement. This arrangement enables a consistent output control depending upon the load for stable lamp operation.

The present invention further discloses a lighting device equipped with the electronic ballast as defined in the above and at least one discharge lamp, and also a lighting system including a plurality of the lighting devices and a controller configured to manage the lighting devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram illustrating an electronic ballast in accordance with a first embodiment of the present invention;

FIG. 2 is a graph illustrating a problem associated with prior art technique of varying a chopper frequency depending upon the number of the discharge lamps;

FIG. 3 is a circuit diagram illustrating another socket applicable to the above electronic ballast;

FIG. 4 is a circuit diagram illustrating a further socket applicable to the above electronic ballast;

FIG. 5 is a graph illustrating variation of an inverter operating frequency of the above electronic ballast with discharge lamps of differing rated powers;

FIG. 6 is a graph illustrating variation of the inverter operating frequency of the above electronic ballast with varying environmental temperature;

FIGS. 7 and 8 are perspective views illustrating a lighting device incorporating the above electronic ballast; and

FIG. 9 is a schematic view illustrating a lighting system using the above lighting devices;

BEST MODE FOR CARRYING OUT THE INVENTION

First embodiment

Referring now to a circuit diagram of FIG. 1, an explanation is made to an electronic ballast in accordance with the first embodiment of the present invention. The electronic ballast is designed to operate two series connected discharge lamps **La1** and **La2**, and includes a filter **10**, a rectifier circuit **20**, a chopper **30**, an inverter **60**, a chopper controller **40**, an inverter controller **70**, and a resonant circuit **80** connected to the inverter **60**. The electronic ballast has its circuit ground **Gnd** connected to a ground earth **E/G** through a capacitor **12**.

AC voltage from a commercial voltage source is converted through a filter **10** and the rectifier circuit **20** of diodes into a pulsating DC voltage. The pulsating DC voltage is supplied to a smoothing capacitor **C4** through an inductor **T1** and a diode **D1** through an on-off operation of a switching element **Q1** of the

chopper **30**. The on-off timing of switching element **Q1** is controlled by chopper controller **40** to develop a generally constant DC voltage across smoothing capacitor **C4**.

The DC power from chopper **30** is converted through on-off operations of switching elements **Q2** and **Q3** of inverter **60** into a high frequency power supplied to resonant circuit **80**. Resonant circuit **80** is composed of an inductor **T2**, capacitors **C7** and **C8** to have its output ends connected to discharge lamps **La1** and **La2**. Discharge lamps **La1** and **La2** are supplied with the high frequency power which is determined by a composite impedance of resonant circuit **80** and discharge lamps **La1** and **La2**, and also by the on-off operation of switching elements **Q2** and **Q3**.

Although a socket is configured to operate the two series-connected discharge lamps as shown in FIG. 1, the socket may be configured, as shown in FIGS. 3 and 4, respectively for single-lamp operation and multiple-lamp operation.

Inverter controller **70** includes a control integrated circuit **IC2** for controlling to make a high frequency on-off operation of switching elements **Q2** and **Q3** of inverter **60**. Further, inverter controller **70** is configured to set a target power determined by the rated power of the discharge lamp and the number of the lamps used. That is, inverter controller **70** includes a power regulating circuit **72** for setting a basic operating frequency of switching elements **Q2** and **Q3** to develop the target power, and a feedback control circuit **74** for adjusting the output power in match with the target power. Feedback control circuit **74** is configured to detect a resonant current flowing through resonant circuit **80** to make the feedback control of the output from inverter **60** based upon the

resonant current. .

Now, a brief explanation is made to structures and functions of chopper **30** and chopper controller **40** which is a control circuit of chopper **30**. Chopper **30** is composed of inductor **T1**, capacitor **C3**, switching element **Q1**, and smoothing capacitor **C4**. Capacitor **C3** is connected across output ends of rectifier **20**, while inductor **T1** is connected in series with switching element **Q1** across the output ends of rectifier **20**. Smoothing capacitor **C4** is connected in series with diode **D1** across smoothing capacitor **Q1** so as to accumulate the smoothed DC voltage through the on-off operation of switching element **Q1**, and give the smoothed DC voltage as an output from chopper **30**. A current detection resistor **R1** is connected to a source terminal of switching element **Q1**.

Chopper controller **40** is provided to give an optimum operation of switching element **Q1**, and has the configuration basically equivalent to a general chopper controlling IC "MC32262", available from Motorola Inc for use as a power factor improving circuit (PFC). The structure of the controlling IC is already known and is not mentioned in detail here. Instead, a brief explanation is made to external components for the controlling integrated circuit **IC1**.

No. 1 pin (output voltage feedback terminal) of controlling integrated circuit **IC1** is adapted to receive smoothed output voltage **V_{dc}** divided by a series circuit of a variable resistor **VR1** and a resistor **R11** connected in parallel with smoothing capacitor **C4**.

No. 2 pin (error amplifier output/ compensation terminal) is connected to a parallel combination of capacitor **C15** and resistor **R14**.

No. 3 pin (multiplier input terminal) is adapted to receive a pulsating voltage of chopper input voltage (voltage across capacitor **C3**) divided by

resistors **R9** and **R10**, and is also connected to capacitor **C14** in parallel with resistor **R10**.

No. 4 pin (current detection input terminal) is adapted to receive a voltage across resistor **R1** through resistor **R13** for detecting the current flowing through switching element **Q1**, and is connected to a capacitor **C16** parallel to resistor **R13**.

No. 5 pin (zero-current detection input terminal) is connected to receive an output from secondary winding of inductor **T1** through resistor **R12** for detecting a zero-cross of the current flowing through inductor **T1**.

No. 6 pin (ground terminal) is connected to circuit ground **Gnd**.

No. 7 pin (output terminal) is connected to a gate terminal of switching element **Q1** through resistors **R3** and **R4** for driving switching element **Q1**.

No. 8 pin (power voltage terminal) is connected to receive a voltage **Vcc** of a power source for the control circuit, which voltage is divided by resistors **R20** and **R21** and smoothed by capacitor **C13** and stabilized by zener diode **ZD1**.

With this configuration, the controlling integrated circuit **IC1** detects the pulsating voltage input to chopper **30** based upon the input to No. 3 pin, the smoothed output voltage from chopper **30** based upon the input to No. 1 pin, the current flowing through switching element **Q1** based upon the input to No. 4 pin, and the current flowing through inductor **T1** based upon the input to No. 5 pin for controlling the operation of switching element **Q1** to develop a predetermined output DC voltage.

Inverter **60** receives the DC voltage developed across the output ends of chopper **30** (smoothed DC voltage V_{dc} across capacitor **C4**) to develop the high frequency AC output. Switching element **Q2** has its drain connected to the

output end of the chopper **30**, and has its source connected to a drain of switching element **Q3**. Source of switching element **Q3** is connected to a detection resistor **R2** for the feedback control circuit. Resistor **R2** is connected to circuit ground **Gnd**. Gates of switching elements **Q2** and **Q3**, and an output end of inverter **60** are connected to inverter controller **70**.

Inverter controller **70** has the structure basically identical to a general controller IC "L6574" with an incorporated operational amplifier available from STMicroelectronics. The structure is known and is not explained here in detail. Instead, a brief explanation will be made to external components for the controller integrated circuit **IC2**.

No. 1 pin (preheating time setting capacitor terminal) of controller integrated circuit **IC2** is connected to a capacitor **C17**, while no. 2 pin (preheating frequency setting resistor terminal) of controller integrated circuit **IC2** is connected to a resistor **R17**. Capacitor **C17** and resistor **R17** give a time constant which determines a preheating frequency.

No. 3 pin (lighting frequency setting capacitor terminal) of controller integrated circuit **IC2** is connected to capacitor **C18**, while no. 4 pin (lighting frequency setting resistor terminal) of controller integrated circuit **IC2** is connected to a variable resistor **VR2** and a resistor **R22**. Capacitor **C18**, variable resistor **VR2** and resistor **R22** give a time constant which determine a lamp operating frequency. Thus, controller integrated circuit **IC2** is cooperative with capacitor **C18**, variable resistor **VR2**, and resistor **R22** to define power regulating circuit **72** which determines the target power supplied to the discharge lamp, i.e., basic operating frequency. The target power (basic operating frequency) can be regulated by varying the resistance of variable resistor **VR2**.

With regard to no. 5 pin (incorporated operational amplifier's output terminal), no. 6 pin (incorporated operational amplifier's input terminal), and no. 7 pin (incorporated operational amplifier's (+) terminal) of controller integrated circuit **IC2**, no. 6 pin is connected to source resistor **R2** of the switching element **Q3** of inverter **60**, and no. 7 pin is connected to receive a voltage from V_{cc} divided by variable resistor **VR3** and resistor **R15** which are connected in parallel with V_{cc} . A parallel circuit of capacitor **C19** and resistor **R19** is connected between no. 5 pin (incorporated operational amplifier's output terminal) and no. 6 pin (incorporated operational amplifier's input terminal), while a series circuit of diode **D4** and resistor **R23** is connected between no. 4 pin (lighting frequency setting resistor terminal) and no. 5 pin (incorporated operational amplifier's output terminal) so as to determine the lamp operating frequency based upon the output level of the operational amplifier. That is, the operational amplifier incorporated in controller integrated circuit **IC2** is cooperative with resistor **R21**, diode **D4**, capacitor **C19**, and resistor **R19** connected respectively to no.5 pin, no. 6 pin, and no. 7 pin of controller integrated circuit **IC2** to define the feedback control circuit **74**, which varies the operating frequency of switching elements **Q2** and **Q3** based upon the value of resonant current flowing into the resonant circuit **80** (equivalent to the current flowing through resistor **R2**) in order to make the feedback control of keeping the output power being supplied to discharge lamps **La1** and **La2** in match with the target power. No. 8 pin and no. 9 pin of controller integrated circuit **IC2** are abnormality detection terminals, of which application is not deemed necessary.

No. 10 pin (ground terminal) of controller integrated circuit **IC2** is connected to the circuit ground **Gnd**.

No. 11 pin (lower switching element driving signal output terminal) of controller integrated circuit **IC2** is connected through resistors **R7** and **R8** to gate of switching element **Q3**.

No. 12 pin (power source lower terminal) of controller integrated circuit **IC2** is connected to Vcc. No. 14 pin (upper switching element driving signal reference voltage terminal) is connected to a node between a source of switching element **Q2** and a drain of switching element **Q3**.

No. 15 pin (upper switching element driving signal output terminal) of controller integrated circuit **IC2** is connected through resistors **R5** and **R6** to gate of switching element **Q2**.

Capacitor **C20** is connected between no. 16 pin (upper switching element driving power terminal) of controller integrated circuit **IC2** and no. 14 pin.

With this arrangement, the controller integrated circuit **IC2**, upon being energized, drives switching elements **Q2** and **Q3** at preheating frequency for preheating time respectively set by controller integrated circuit **IC2** to turn on the discharge lamp. After the discharge lamp is turned on, the feedback control circuit **74** receives a signal representing the current flowing through switching element **Q3** to modify the operating frequency of inverter **60** based upon the lighting frequency set by the power regulating circuit **72** to obtain the output power in match with the target power.

The electronic ballast of the present embodiment includes, in addition to the resonant circuit **80**, a preheating circuit **90** for preheating filaments of the discharge lamps. The resonant circuit **80** includes a series combination of a resonant inductor **T2** and a resonant capacitor **C7** connected across the output ends (Vs-Gnd) of inverter **60**, and a DC blocking capacitor **C8** connected in

series with discharge lamps **La1** and **La2** across capacitor **C7**. Inductor **T2** and capacitor **C7** constitute a first resonant circuit. Capacitor **C8** is connected in series with inductor **T2** and the discharge lamps across the output ends of inverter **60** to constitute a second resonant circuit. The capacity ratio of capacitor **C7** to capacitor **C8** is set as $C7 < C8$.

Preheating circuit **90** includes a resonant inductor **T3**, a capacitor **C6**, and a switching element **Q4** with a primary winding of resonant inductor **T3** connected across switching element **Q3** (between V_s - Gnd) through capacitor **C6** and switching element **Q4**. The discharge lamps **La1** and **La2** have their unshared filaments connected respectively to the two secondary windings of resonant inductor **T3** through capacitors **C9** and **C11**. Another secondary winding of resonant inductor **T3** is connected to shared filaments of discharge lamps **La1** and **La2** through capacitor **C10**.

The resonant circuit **80** functions differently depending upon the function of inverter **60**. The resonant circuit **80** gives a resonant curve, as shown in FIG. 5 which is given for two kind of discharge lamps A (FHF32-32W rated power) and B (FL40ss/36 – 40W rated power).

Until turning on the lamp on after being energized, the inverter controller **70** causes inverter **60** to switch the operating frequency from a preheating mode (and starting mode) to a lighting mode (frequency being determined by a minimum frequency f_{min} and regulated by feedback control circuit), thereby lighting the discharge lamps. After lighting the lamp, the feedback control circuit **74** varies the operating frequency of inverter **60** based upon the current flowing through switching element **Q3** (equivalent to the current flowing into resonant circuit **80**). Thus, the operating frequency of inverter **60** varies by Δf for the

discharge lamps A and B of different loads, as shown in FIG. 5, thereby varying the output power correspondingly by ΔW in order to provide the optimum output power to the discharge lamps in accordance with the rated power thereof. Also when the number of the discharge lamps changes, the feedback control circuit **74** acts to vary the operating frequency of inverter **60** depending upon the level of the current flowing into the resonant circuit, thereby giving the output power in match with the target power determined by power regulating circuit **72**.

The operating frequency varies within a limited range determined by the target power so as to avoid excessive variation of the operating frequency and therefore avoid undue increase of switching loss at each of switching elements **Q2** and **Q3**.

As is explained in the above, the feedback control of inverter **60** is made to obtain optimum output power depending upon the load power requirement such that the chopper **30** can be only required to regulate basically for providing a constant output voltage. With this result, even in a situation where the load power varies considerably, for example, due to varying number of the lamps, it is only required to regulate the frequency within the operating frequency range (operating frequency range of switching element **Q1**) of the chopper **30** defined by the controller integrated circuit **IC1** used in chopper controller **40**, thereby eliminating the need of altering the circuit configuration of chopper **30** itself and realizing that the electronic ballast of the single circuit design can cover the different load power.

Although the illustrated embodiment utilizes the source resistor of switching element **Q3** for detection of the resonant current flowing into the resonant circuit **80**, any other equivalent scheme may be utilized for the same

purpose. For example, a composite current of the lamp current and that through capacitor **C7** can be utilized as equivalent to the resonant current in the arrangement of FIG.1.

Further, the present embodiment includes a temperature coefficient resistor **TC** (thermistor) which is added as a temperature sensor to a series resistor network composed of resistor **R15** and variable resistor **VR3** to give a reference voltage to the feedback control circuit **74** of inverter controller **70**, in order to compensate for impedance variation due to change of environmental temperature for keeping the constant output power.

When the discharge lamp sees impedance variation due to the change of the environmental temperature, i.e., the environmental temperature becomes low or high from an optimum temperature (25 °C, for example), the feedback control circuit **74** acts to shift a curve of indicating the output power in relation to the operating frequency towards a lower frequency by Δf , as shown in FIG. 6, thus compensating for ΔW and providing the output power in match with the target power set at the power regulating circuit **72**.

Although the present embodiment illustrates the use of separate controller integrated circuits respectively for chopper controller **40** and inverter controller **70**, it is equally possible to use an one-chip integrated circuit combining these controller integrated circuit.

FIGS. 7 and 8 show one example of a lighting device incorporating the above-described electronic ballast for the discharge lamp. The electronic ballast is realized by the above-mentioned various electronic components mounted on a printed circuit board **110**, and is accommodated within a case **100** to be supplied with AC power at input terminal **120**. The case **100** is provided on its bottom

with lamp sockets **102** for supplying the output power to the discharge lamps **La1** and **La2** inserted to the sockets.

FIG. 9 shows a lighting system using a plurality of the above lighting devices **L** and a managing device **M** equipped with human detection sensors and a programmable system. The managing device **M** is configured to turn on the lamps upon detection of the human by the human detection sensor, and turn off the lamps upon detection of non-presence of the human, or even configured to turn on some of the lamps according to a time zone for efficient lighting management with realization of energy-savings.

Claims

1. An electronic ballast for operating at least one discharge lamp, said ballast comprising:

a rectifier configured to rectify an AC voltage to give a DC voltage;

a chopper including an inductor, a capacitor and a switching element which is controlled to repetitively interrupt the DC voltage from the rectifier through said inductor to develop a constant DC voltage across said capacitor;

an inverter including at least one switching element which is controlled to turn and off at a suitable switching frequency so as to convert said DC voltage from said chopper into a high frequency AC voltage,

a resonant circuit including an inductor and a first capacitor and being configured to resonate said high frequency AC voltage to develop a resonated AC voltage to be applied to at least one discharge lamp for operating thereof; wherein said ballast includes:

a power adjustor configured to designate a target power in match with a power requirement determined by said at least one discharge lamp; and

an inverter controller configured to monitor a resonant index indicative of a resonant current flowing into said resonant circuit and to vary said switching frequency of said inverter in a feedback manner based upon said resonant index for keeping an output power applied to said at least one discharge lamp at said target power.

2. An electronic ballast as set forth in claim 1, further including:

a temperature sensor configured to detect an environmental temperature,

said inverter controller being configured to vary said switching frequency also based upon said environmental temperature for keeping said output power applied to said at least one discharge lamp at said target power.

3. An electronic ballast as set forth in claim 1, wherein said resonant circuit comprises a first resonant circuit composed of said inductor and said first capacitor connected in series across an output of said inverter, and a second resonant circuit composed of a second capacitor connected in series with said at least one discharge lamp across said first capacitor.

4. An electronic ballast as set in any one of claims 1 to 3, wherein said inverter controller is configured to vary said switching frequency within a predetermined range which varies with said power requirement.

5. A lighting device comprising said electronic ballast as defined in any one of claims 1 to 3, and said at least one discharge lamp.

6. A lighting system comprising a plurality of said lighting devices as defined in claim 5, and a controller configured to manage said lighting devices.