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(54) **LED LIGHT SOURCE**

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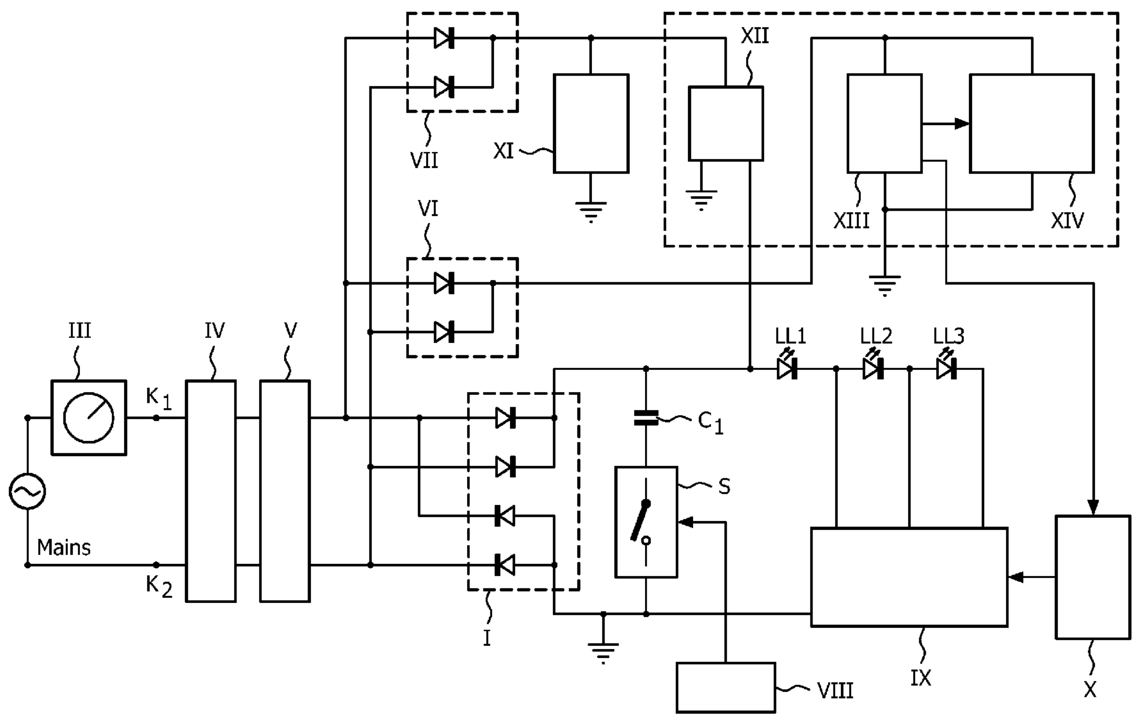
(57) **ABSTRACT**

LED light source suitable for use with a phase cut dimmer (III), comprising •input terminals (K1, K2) for connection to an AC supply voltage, •a rectifier (I) coupled to the input terminals, **108** a series arrangement comprising N LEDs (LL**1**, LL**2**, LL**3**) coupled to the rectifier, •control circuitry (EX) for sequentially activating (deactivating) the LEDs as the supply voltage increases (decreases), wherein the control circuitry comprises: •N controllable current regulators, each regulator being coupled between the cathode of a LED and ground and comprising a transistor and one impedance in series, •a global current control circuit (X) coupled to the control electrodes of said transistors and comprising circuitry for adjusting the voltage at said control electrodes in dependency of the phase angle, •a series arrangement of a switch (S) and a capacitor (C**1**) coupled- to the rectifier and •means (VIII) for rendering said switch conductive in case the AC supply voltage drops below a reference value.



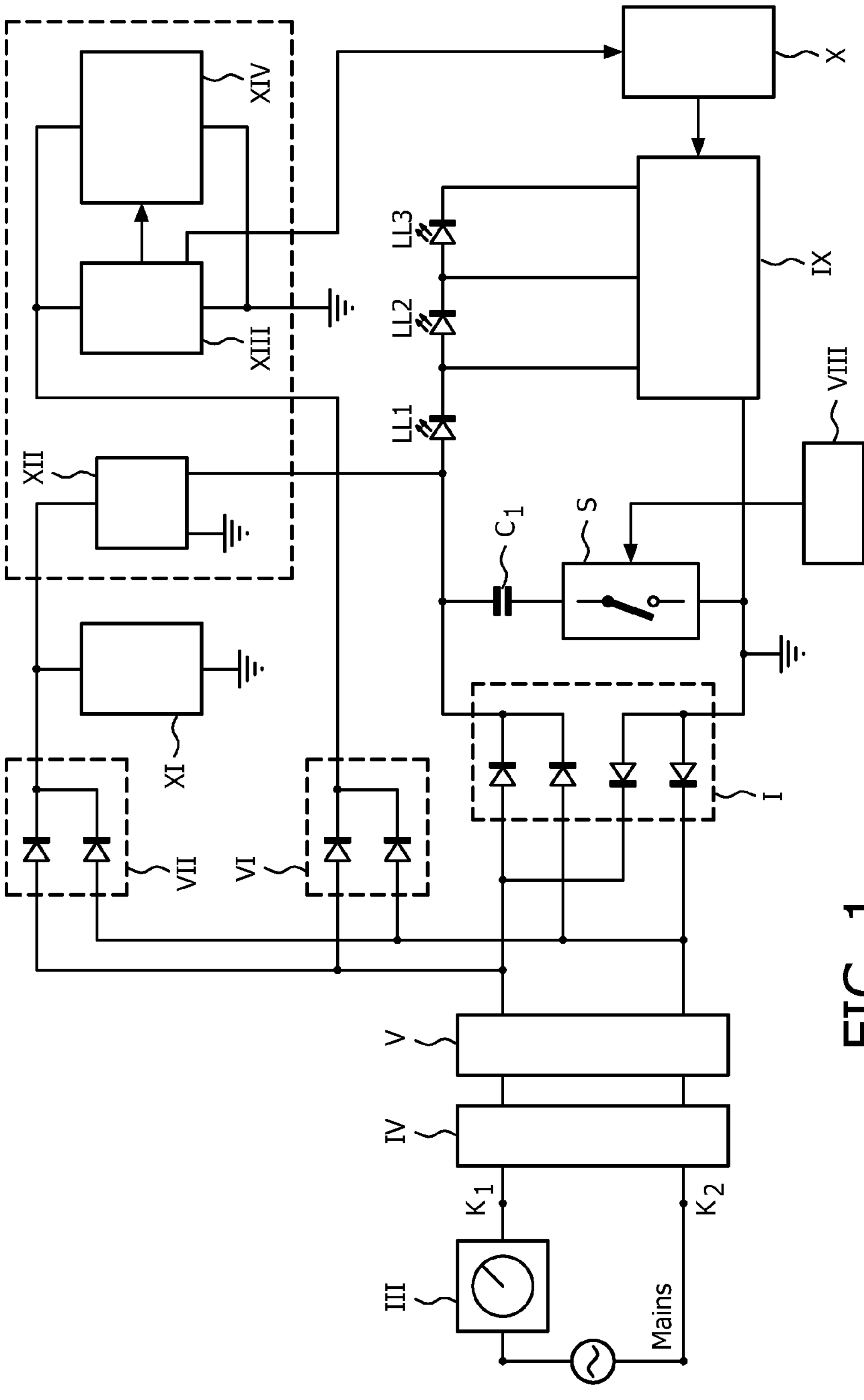

XIV
XIII
XII
XI
X
IX
VIII
VII
VI
V
IV
III
I
S
C_1
LL1
LL2
LL3
K_1
K_2
Mains

FIG. 1

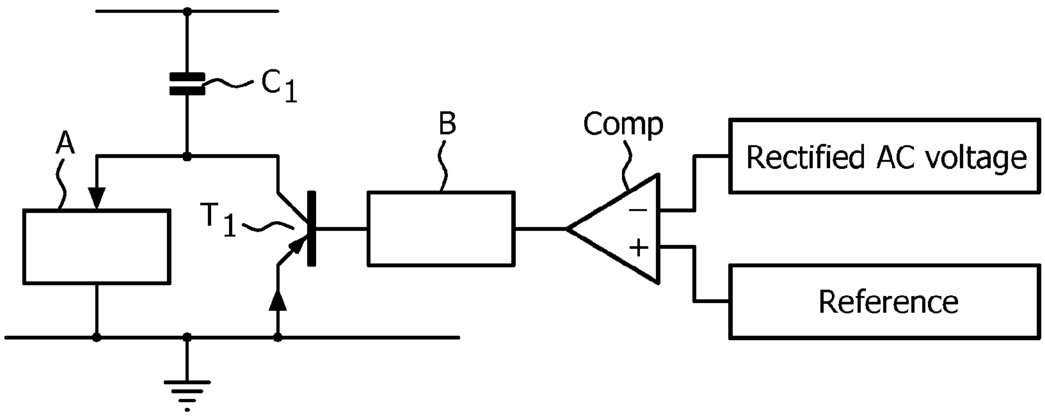


FIG. 2

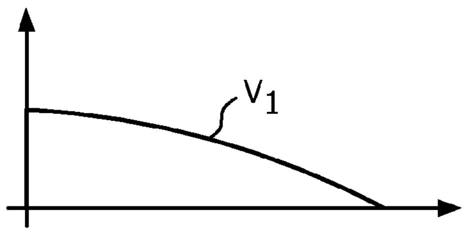


FIG. 3a

FIG. 3b

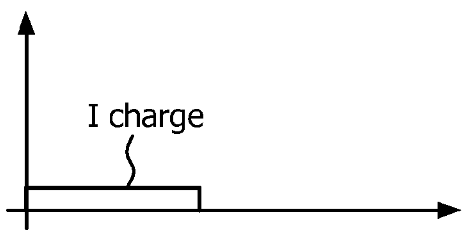


FIG. 3c

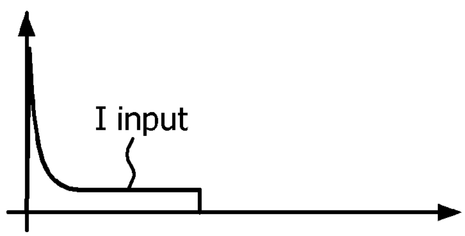


FIG. 3d

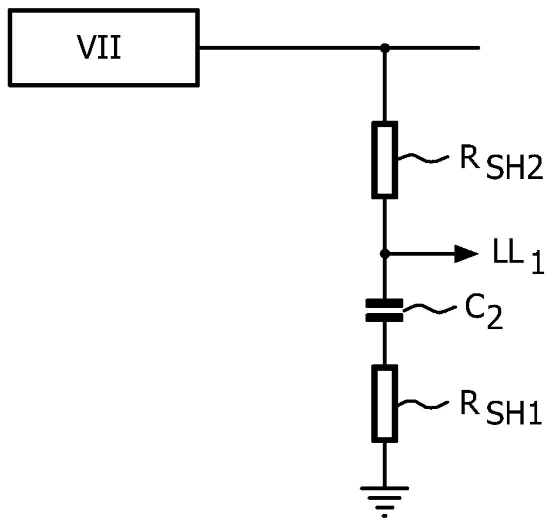


FIG. 4

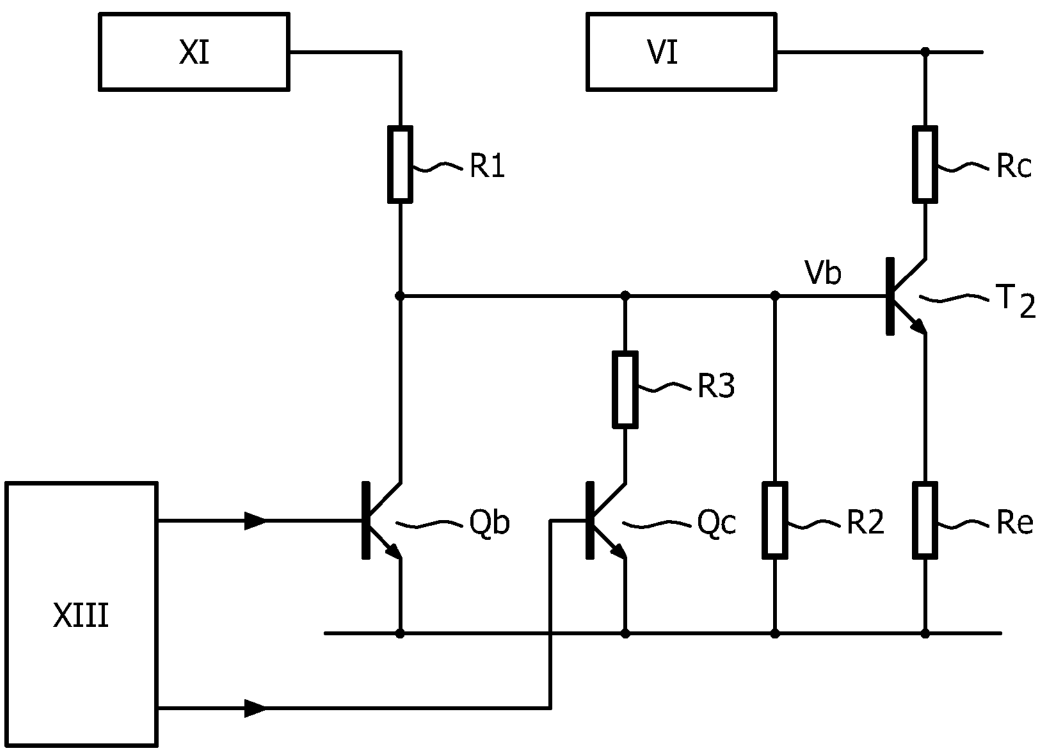


FIG. 5

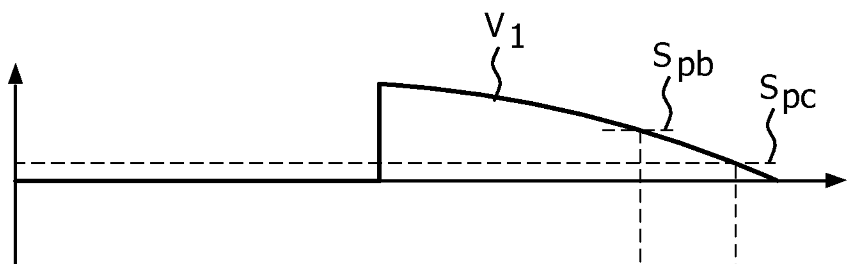


FIG. 6a

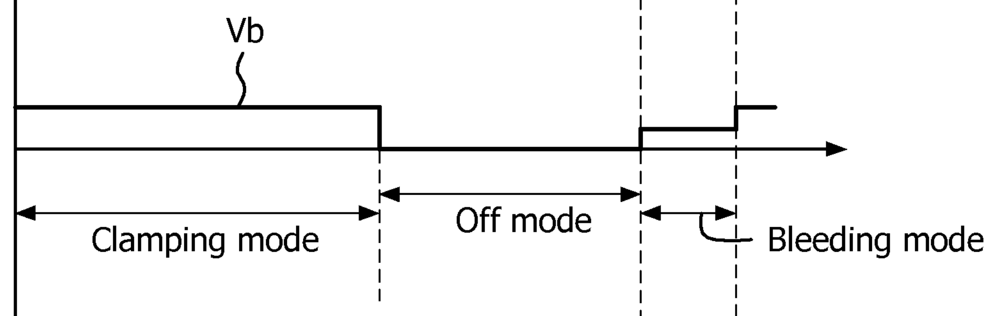


FIG. 6b

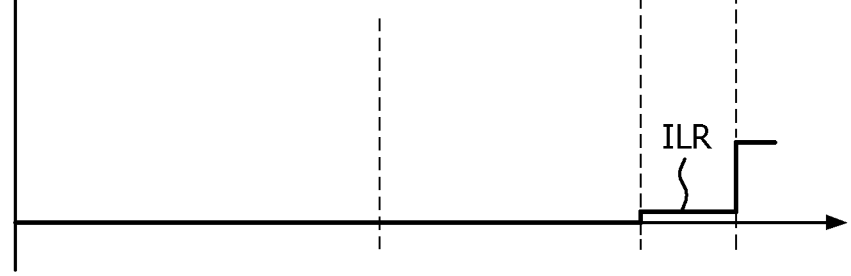


FIG. 6c

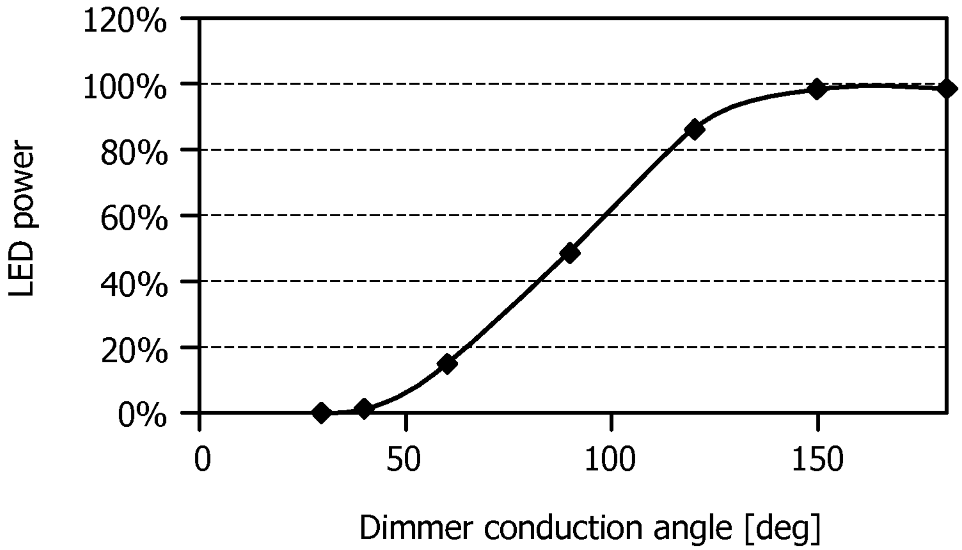

120%
100%
80%
60%
40%
20%
0%
LED power
0
50
100
150
Dimmer conduction angle [deg]

FIG. 7

LED LIGHT SOURCE

FIELD OF THE INVENTION

[0001] The invention relates to a cheap and simple LED light source comprising N LED loads that is directly connectable to a supply source supplying a low frequency AC voltage such as the mains supply.

BACKGROUND OF THE INVENTION

[0002] Such a LED light source is known from U.S. Pat. No. 7,081,722 B1. The LED loads are LED arrays comprising series arrangements and possibly parallel arrangements of individual LEDs. The known LED light source comprises a rectifier for rectifying the low frequency AC supply voltage. A series arrangement comprising the N LED loads is connected to output terminals of the rectifier. During operation a periodical DC voltage with an instantaneous value varying between zero Volt and a maximum amplitude is present between the output terminals of the rectifier. The known LED light source is equipped with control means for subsequently making the LED loads conduct a current, one by one and starting with a first LED load that is closest to a first end of the series arrangement, in dependency of the instantaneous value of the low frequency AC supply voltage when the instantaneous value increases and for subsequently making the LED loads stop conducting a current, one by one and starting with the Nth LED load, in dependency of the instantaneous value of the low frequency AC supply voltage when the instantaneous value decreases. These control means typically comprise N control strings, each comprising a transistor and being coupled between the cathode of one of the LED loads and an output terminal of the rectifier.

[0003] When the instantaneous value of the periodical DC voltage is zero Volt, all of the transistors comprised in the control strings are conductive but none of the LED loads carries a current. When the instantaneous value of the periodical DC voltage increases, a voltage is reached at which a first LED load and the first transistor comprised in the first control string start conducting a current. Similarly, when the instantaneous value of the periodical DC voltage has increased further to a high enough value, the second LED load and the transistor in the second control string start conducting. In order to minimize power dissipation it is desirable to make sure that the current through the first control string is reduced and preferably stopped.

[0004] In the case of further increase of the instantaneous value of the periodical DC voltage, the remaining LED loads and the transistors comprised in the control strings connected to the cathodes of these LED loads subsequently start conducting a current. When the nth control string carries a current, the control means ensure that the currents in the first n−1 control strings are reduced or stopped. When all of the LED loads conduct a current, the Nth transistor conducts a current and the instantaneous value of the periodical DC voltage increases further until the maximum amplitude is reached. After that the instantaneous value of the periodical DC voltage starts decreasing. While the instantaneous value decreases, the LED loads stop conducting a current one by one in reversed order (first the Nth LED load stops conducting and the first LED load is the last to stop conducting). When the nth LED load stops conducting, the (n−1)th control string starts conducting a current. The nth transistor remains conductive but no longer carries a current or only carries a strongly reduced current. After the first LED load has stopped conducting, all transistors are conductive but none conducts a current, the instantaneous value of the periodical DC voltage decreases further to zero and then the cycle described hereabove is repeated. The known LED light source is very compact and comparatively simple. Furthermore, it can be directly supplied from a low frequency AC supply voltage source such as the European or American mains supply.

[0005] Dimming of a LED light source according to the invention can for instance be effected by adjusting the voltage present at the control electrodes of the transistors comprised in the control strings via the global current control circuit. However, it is generally desirable that the LED light source is not just dimmable but suitable for use with a phase cut dimmer such as a TRIAC dimmer.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide a LED light source that can be dimmed making use of a phase cut dimmer such as a TRIAC dimmer.

[0007] According to a first aspect of the invention A LED light source is provided, suitable for use with a phase cut dimmer such as a TRIAC dimmer, and comprising

- **[0008]** a first input terminal and a second input terminal for connection to a supply voltage source supplying a low frequency AC supply voltage with frequency f,
- **[0009]** a rectifier coupled to the input terminals for rectifying the low frequency AC supply voltage,
- **[0010]** a series arrangement comprising N LED loads, a first and second end of said series arrangement being coupled to a first output terminal and a second output terminal of the rectifier,
- **[0011]** control circuitry for subsequently making the LED loads conduct a current, one by one, in dependency of the instantaneous value of the low frequency AC supply voltage when the instantaneous value increases and for subsequently making the LED loads stop conducting a current, one by one, in dependency of the instantaneous value of the low frequency AC supply voltage when the instantaneous value decreases, wherein the control circuitry comprises
- **[0012]** a global current control circuit coupled to the controllable current regulators for controlling the instantaneous value of the current through the control strings, wherein the controllable current regulators each comprise a series arrangement of a transistor and at least one impedance, and wherein the global current control circuit is coupled to the control electrodes of the transistors comprised in the controllable current regulators and comprises circuitry for adjusting the voltage present at the control electrodes of the transistors comprised in the control strings, in dependency of the adjusted phase angle of the phase cut dimmer, and
- **[0013]** a series arrangement of a switch and a capacitor coupled between the output terminals of the rectifier and control circuitry for rendering the switch conductive in case the instantaneous value of the low frequency AC supply voltage drops below a reference value.

[0014] During operation, the capacitor is charged to nearly the peak value of the rectified mains voltage and it supplies energy to the LED loads when the rectified mains voltage has dropped below the reference value. Stroboscopic effects are thereby suppressed. By controlling the voltage at the control electrodes of the transistors comprised in the controllable current regulators in dependency of the adjusted phase angle of the phase cut dimmer, it is possible to dim the LED light source by adjusting the phase angle of the phase cut dimmer.

[0015] According to a further aspect, a method is provided for supplying a LED light source, comprising the steps of

- **[0016]** providing a supply voltage source supplying a low frequency AC supply voltage with frequency f,
- **[0017]** rectifying the low frequency AC supply voltage,
- **[0018]** providing a series arrangement of a switch and a capacitor coupled between the output terminals of the rectifier and control circuitry for rendering the switch conductive in case the instantaneous value of the low frequency AC supply voltage drops below a reference value,
- **[0019]** supplying the rectified AC supply voltage to a series arrangement of N LED loads,
- **[0020]** supplying the voltage across the capacitor to the series arrangement of N LED loads, when the instantaneous value of the low frequency AC supply voltage drops below the reference value,
- **[0021]** subsequently making the LED loads conduct a current, one by one, in dependency of the instantaneous value of the supplied voltage when the supplied voltage increases and subsequently making the LED loads stop conducting a current, one by one, in dependency of the instantaneous value of the supplied voltage when the instantaneous value of the supplied voltage decreases,
- **[0022]** providing N control strings comprising a series arrangement of a transistor and an impedance and coupled between the cathode of a LED load and the second output terminal of the rectifier, and
- **[0023]** controlling the instantaneous value of the current through the control strings by controlling the voltages at the control electrodes of the transistors comprised in the control strings.

The method has the same advantages as the LED light source according to the first aspect.

[0024] Preferably a LED light source according to the invention comprises a current bleeder for providing a conductive path for a TRIAC dimmer, when used in combination with such a dimmer. Wrong triggering of the TRIAC comprised in a TRIAC dimmer causing light flickering is thereby prevented. The current bleeder draws a current higher than the holding current of the TRIAC so that multi-triggering of the TRIAC (also causing light flickering) is also prevented.

[0025] Preferably a LED light source according to the invention comprises a clamping circuit to enable correct functioning of a timer comprised in a TRIAC dimmer, when the LED light source is used in combination with such a TRIAC dimmer.

[0026] More preferably the current bleeder and the clamping circuit are combined into one linear current source.

[0027] A LED light source according to the invention preferably comprises a damping circuit for damping an oscillation in an oscillation circuit formed by an inductive element and a capacitor comprised in an EMI filter in a TRIAC dimmer, when the LED light source is used in combination with such a TRIAC dimmer. These oscillations, when not sufficiently damped, cause malfunctioning of the TRIAC dimmer.

[0028] Preferably a LED light source according to the invention comprises an RC shunt circuit to draw a current from a TRIAC dimmer when the TRIAC is triggered, in the case that the LED light source is used in combination with such a dimmer. It is thereby prevented that the firing of the TRIAC is unsuccessful which might result in multi-firing of the TRIAC which in turn causes light flicker. In addition, the RC shunt circuit helps also to effectively damp the oscillation at the moment when the TRIAC is triggered.

[0029] As explained hereabove, a LED light source according to the invention comprises a series arrangement of a switch and a capacitor, coupled between the output terminals of the rectifier, and control circuitry for rendering the switch conductive in case the instantaneous value of the low frequency AC supply voltage drops below a reference value. The capacitor is referred to as fill-in capacitor and is used as a supply voltage source, when the instantaneous value of the low frequency AC supply voltage is too low for causing a current to flow through any of the LED loads. When the LED light source is not dimmed, this happens directly before and after the zero crossing of the mains supply voltage. Both the occurrence of light flicker and stroboscopic effect are thereby prevented. In case the LED light source is used in combination with a TRIAC dimmer, the LED light source preferably further comprises a linear regulator to control the charging current of the capacitor. The linear regulator controls the charging current at a level that is low compared to the repetitive current flowing through the RC shunt, so a too high total current causing damage to the dimmer and possibly audible noise generated by the dimmer is prevented.

[0030] A LED light source according to the invention comprising a number of the features or all the features mentioned here-above to make the LED light source compatible with a TRIAC dimmer preferably comprises one or more half bridge rectifiers. By configuring different features such as for instance the fill-in capacitor and the RC shunt at the output of different rectifiers, the operation of each feature is not interfered with by the operation of the others, so that proper operation of all features is obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] Embodiments of a LED light source according to the invention will be further discussed with reference to a drawing.

[0032] In the drawing,

[0033] FIG. **1** shows an embodiment of a LED light source according to the invention, suitable for use in combination with a TRIAC dimmer together with the TRIAC dimmer,

[0034] FIG. **2** shows a schematic representation of a fill in capacitor and control circuitry for charging and discharging of the fill in capacitor,

[0035] FIG. **3** shows a number of signals occurring during operation of the

[0036] embodiment shown in FIG. **1** as a function of time,

[0037] FIG. **4** shows an RC shunt comprised in the embodiment shown in FIG. **4**,

[0038] FIG. **5** shows an embodiment of a combined bleeding and clamping circuit comprised in the embodiment shown in FIG. **1**,

[0039] FIG. **6** shows some signals occurring during the operation of the circuit shown in FIG. **8**, and

[0040] FIG. **7** shows an exemplary relation between the phase angle of a TRIAC

[0041] dimmer and the power consumed by the LED loads.

DETAILED DESCRIPTION OF THE INVENTION

[0042] In FIG. **1**, K1 and K2 are first and second input terminals for connection to a supply voltage source supplying a low frequency AC supply voltage. K1 and K2 are connected to the mains via a TRIAC dimmer III and are also coupled to the input terminals of a rectifier I, a first half bridge rectifier VI and a second half bridge rectifier VII via a damper IV and a surge protector V. The damper comprises resistors and will partially suppress the oscillation resulting from the triggering of the TRIAC dimmer. Surge protector V contains for instance a metal-oxide varistor or a gas discharge tube and will partially suppress mains transients and bursts.

[0043] Fill in capacitor C**1** and switch S are connected between output terminals of the rectifier I. Circuit part VIII is coupled to switch S and is the control circuitry for switch S. LL**1**, LL**2** and LL**3** are three LED loads in series arrangement and circuit part IX represents control circuitry for controlling the current through one or more LED loads in dependency of the instantaneous value of the rectified AC voltage. This control circuitry typically comprises N control strings, each comprising a transistor and coupled between the cathode of one of the LED loads and an output terminal of the rectifier and circuitry for controlling the conductive state of the transistors. A possible implementation of such circuitry is for instance disclosed in FIG. **8** of U.S. Pat. No. 7,081,722. It is realized by placing an impedance, preferably a resistor, in series with the transistor in each control string and arrange all the resistors in series between the transistor comprised in the first control string and the second output terminal of the rectifier. In addition the control electrodes of the transistors in the control strings comprised in circuit part IX are coupled to a global current control circuit, that is circuit part X in FIG. **1**. Circuit part XI is a low voltage supply. Circuit part XII is an RC shunt having an output coupled to an anode of the first LED load LL**1**. Circuit part XIII is a voltage detection circuit having an output coupled to circuit part X and having an output coupled to circuit part XIV. Circuit part XIV is a combined bleeder and clamping circuit. To prevent interference, circuit parts XIII and XIV are coupled to an output of the first half rectifier bridge VI and circuit parts XI and XII are coupled to an output of the second half rectifier bridge VII.

[0044] In FIG. **2** COMP is a comparator for comparing the instantaneous value of the rectified AC voltage with a reference. An output terminal of the comparator is connected to a control electrode of transistor T**1** via a level shifter B. When the rectified AC voltage is lower than the reference, transistor T**1** is made conductive and capacitor C**1** functions as a temporary supply voltage source for the LED loads. When the rectified AC voltage is higher than the reference, transistor T**1** is non-conductive and capacitor C**1** is charged by linear current regulator A.

[0045] The top curve V1 in FIG. **3***a* is the input phase cut voltage present between input terminals K1 and K2 of the LED light source. The second curve I shunt (FIG. **3***b*) is the current through the RC shunt when the TRIAC is triggered. The third curve Icharge is the current charging capacitor C**1**. The fourth curve (Iinput) is the sum of the currents through the RC shunt Ishunt and the charging current Icharge of capacitor C**1**. It can be seen that the highest magnitude of this sum current I input is mainly determined by the current through the RC shunt and is therefore not high enough to be outside the specification range of the dimmer.

[0046] FIG. **4** shows the RC shunt consisting of a series arrangement of resistor Rsh**1**, capacitor C**2** and resistor Rsh**2**, coupled between second half rectifier bridge VII and ground. A common terminal of resistor Rsh**2** and capacitor C**2** is coupled to the anode of LED load LL**1**. The combined bleeder and clamping circuit shown in FIG. **5** comprises a linear regulator equipped with a series arrangement of resistor Rc, transistor T**2** and resistor Re, coupled between the first half rectifier bridge VI and ground. The voltage at the base terminal of transistor T**2** is controlled by a circuit comprising resistors R**1**, R**2** and R**3** and transistors Qb and Qc. This circuit is supplied by low voltage supply XI and the signals controlling transistors Qb and Qc are generated by the voltage detection circuit XIII. Both Qb and Qc are maintained in a conductive state by the voltage detection circuit XIII when the input phase cut voltage is high. As a consequence hardly any current flows into the base terminal of transistor T**2** and the linear regulator carries no current. When the instantaneous value of the input phase-cut voltage decreases to a value that equals a setpoint for bleeding, transistor Qb is made non-conductive. As a consequence current flows into the base terminal of transistor T**2** and the linear regulator conducts a current. When the instantaneous value of the phase cut input voltage decreases further and a setpoint for clamping is reached, transistor Qc is also switched off. More current flows into the base terminal of transistor T**2** and the linear regulator now carries a much higher current. When the phase cut input voltage drops to zero, the current through the linear regulator also drops to almost zero and remains almost zero during the first part of the next half period of the input voltage since the instantaneous value of the phase cut input voltage is then almost zero. In fact, when the TRIAC is not conducting, the internal timing circuit of the dimmer is still connected between the mains voltage and the LED light source. So the clamping circuit provides a low impedance path for the dimmer timing circuit, though there is almost no current flowing through the clamping circuit.

[0047] When the TRIAC is triggered, the instantaneous value of the phase cut input voltage is higher than zero again and both transistors Qb and Qc are maintained in a conductive state until the instantaneous value of the phase cut input voltage drops to a value equal to the setpoint for bleeding once more. The cycle is illustrated in FIG. **6**. The curve in FIG. **6***a* shows the input phase cut voltage as a function of time and also the setpoints for bleeding (Spb) and clamping (Spc). The second curve (FIG. **6***b*) shows the voltage Vb at the base electrode of transistor T**2** as a function of time. The last curve in FIG. **6***c* shows the current through the regulator Ilr as a function of time.

[0048] For TRIAC dimmer compatibility it is necessary that the conduction angle of the TRIAC dimmer is translated into a voltage that is present on the control electrodes of the transistors comprised in the control strings of the control circuitry of the LED light source. The instantaneous value of this signal determines the current through the LED loads. This signal must be varied as a function of the dimmer conduction angle and can for instance be derived from the dimmer conduction angle as follows. The dimmer conduction angle is detected by sensing the rectified input voltage through a comparator. This angle information then controls a transistor and resistor network coupled to the low voltage supply. The output voltage of this network is a pulse width modulated signal, whose duty cycle corresponds to the dimmer conduction angle, i.e. maximum duty cycle at dimmer highest setting (maximum output power), and smallest duty cycle at lowest setting. The resulting signal is then averaged through an RC network. Furthermore, a saturation circuit is placed; the averaged signal will be clamped at certain level. As a result, the dimming curve shows a flat part in the region close to the maximum output power. This is useful to achieve a matched maximum light output between different dimmers (the maximum achievable conduction angle is different from dimmer to dimmer). Finally, the averaged DC signal is used to control the control strings through a voltage follower which performs impedance matching and increases driving capability.

[0049] FIG. **7** illustrates an obtained dimming curve, showing the relative power consumed by the LED loads as a function of the dimmer conduction angle. The effect of clamping is shown in that the LED power does not increase when the conduction angle exceeds 150 degrees.

1. A LED light source, for use with a phase cut dimmer comprising:

a first input terminal and a second input terminal for connection to a supply voltage source supplying a low frequency AC supply voltage with frequency f,

a rectifier coupled to the input terminals for rectifying the low frequency AC supply voltage,

a series arrangement comprising N LED loads, a first and second end of said series arrangement being coupled to a first output terminal and a second output terminal of the rectifier,

control circuitry for subsequently making the LED loads conduct a current, one by one, in dependence on the instantaneous value of the low frequency AC supply voltage when the instantaneous value increases and for subsequently making the LED loads stop conducting a current, one by one, in dependence on the instantaneous value of the low frequency AC supply voltage when the instantaneous value decreases,

wherein the control circuitry comprises

each N control strings comprising a controllable current regulator and being coupled between the cathode of a respective LED load and the second output terminal of the rectifier, and

a global current control circuit coupled to the controllable current regulators for controlling the instantaneous value of the current through the control strings, wherein the controllable current regulators each comprise a series arrangement of a transistor and at least one impedance, and wherein the global current control circuit is coupled to the control electrodes of the transistors comprised in the controllable current regulators and comprises circuitry for adjusting the voltage present at the control electrodes of the transistors comprised in the control strings, in dependency of the adjusted phase angle of the phase cut dimmer, wherein

a series arrangement of a switch and a capacitor coupled between the output terminals of the rectifier and control circuitry for rendering the switch conductive in case the instantaneous value of the low frequency AC supply voltage drops below a reference value; and

wherein the phase cut dimmer is a TRIAC dimmer and the LED light source comprises an RC shunt circuit for providing reliable latching of the TRIAC dimmer.

2. The LED light source as claimed in claim **1**, wherein the LED light source comprises a current bleeder for providing a conductive path for the phase cut dimmer.

3. The LED light source as claimed in claim **1**, wherein the LED light source comprises a clamping circuit to enable correct functioning of a timer comprised in the phase cut dimmer.

4. The LED light source as claimed in claims **2**, wherein the current bleeder and the clamping circuit are combined into one linear current source.

5. The LED light source as claimed in claim **1**, wherein the LED light source comprises a damping circuit for damping an oscillation in an oscillation circuit formed by an inductive element and a capacitor comprised in an EMI filter in the phase cut dimmer.

6. (canceled)

7. The LED light source as claimed in claim **1**, wherein the LED light source further comprises a linear regulator to control the charging current of the capacitor.

8. The LED light source as claimed in claim **7**, wherein the LED light source comprises two half bridge rectifiers.

9. A method for supplying a LED light source, comprising the steps of:

providing a supply voltage source supplying a low frequency AC supply voltage with frequency f,

rectifying the low frequency AC supply voltage,

supplying the rectified AC supply voltage to a series arrangement of N LED loads,

supplying the voltage across the capacitor to the series arrangement of N LED loads, when the instantaneous value of the low frequency AC supply voltage drops below the reference value,

subsequently making the LED loads conduct a current, one by one, in dependency of the instantaneous value of the supplied voltage when the supplied voltage increases and subsequently making the LED loads stop conducting a current, one by one, in dependency of the instantaneous value of the supplied voltage when the instantaneous value of the supplied voltage decreases,

providing N control strings, each control string comprising a series arrangement of a transistor and an impedance and coupled between the cathode of a respective LED load and the second output terminal of the rectifier, and

controlling the instantaneous value of the current through the control strings by controlling the voltages at the control electrodes of the transistors comprised in the control strings, further comprising the steps of

providing a series arrangement of a switch and a capacitor coupled between the output terminals of the rectifier and control circuitry for rendering the switch conductive in case the instantaneous value of the low frequency AC supply voltage drops below a reference value,

providing a TRIAC dimmer, wherein the LED light source comprises an RC shunt circuit for providing reliable latching of the TRIAC dimmer.

* * * * *