(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 September 2011 (09.09.2011)

PCT

(10) International Publication Number
WO 2011/108876 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/KR2011/001488

(22) International Filing Date: 4 March 2011 (04.03.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10-2010-0019358 4 March 2010 (04.03.2010) KR
10-2011-0011972 10 February 2011 (10.02.2011) KR

(71) Applicant (*for all designated States except US*): **KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY** [KR/KR]; 335 Gwahangno Yuseong-gu, Daejeon 305-701 (KR).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **RIM, Chun-Taek** [KR/KR]; Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu, Daejeon 305-701 (KR). **KIM, Bong-Cheol** [KR/KR]; 201-701 Mido Apt., Daechi 2-dong, Gangnam-gu, Seoul 135-837 (KR). **HUH, Jin** [KR/KR]; Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu 305-701 (KR). **KIM, Yun-Ho** [KR/KR]; 591-399 Yangho-dong, Gumi-si, Gyeongsangbuk-do 730-390 (KR). **LEE, Byung-Hun** [KR/KR]; Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu 305-701 (KR). **KIM, Hyun-Jae** [KR/KR]; Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu 305-701 (KR). **LEE, Woo-Young** [KR/KR]; Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu 305-701 (KR).

(74) Agent: **CHANG, Sue-Hyun**; 3rd Fl., Samhwa Bl., 738-43, Yeoksam-dong, Gangnam-gu, Seoul 135-080 (KR).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

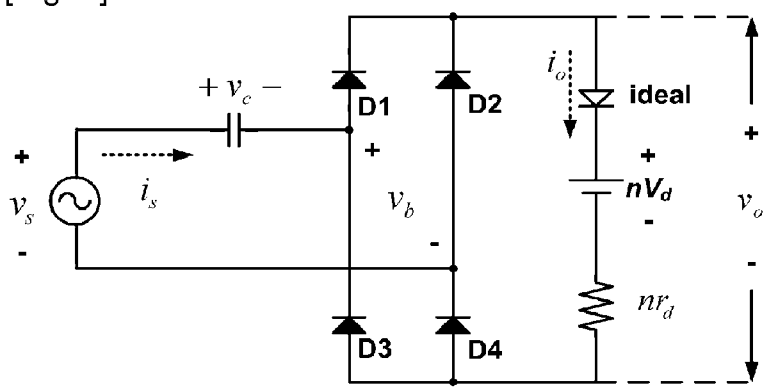
(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: DRIVING APPARATUS FOR LIGHT EMITTING DIODES

[Fig. 4]



(57) Abstract: A driving apparatus for light emitting diodes is disclosed. The driving apparatus for light emitting diodes (LEDs) includes: at least one capacitor connected in series with an AC power source to limit current; and a first LED array and a second LED array connected in series with the capacitor, wherein the first LED array and the second LED array are connected in parallel and have opposite polarities, wherein the voltage drop of the LED arrays is one half the maximum voltage of the AC power source. The LED driving apparatus operates using an AC power source on the basis of a simple driving circuit, is insensitive to changes in temperature and source voltage, may be manufactured at low costs, consumes only a small amount of power, has good characteristics in relation to harmonics of input current and power factor, and operates at a high frequency in a flicker-free way.

WO 2011/108876 A2

Description

Title of Invention: DRIVING APPARATUS FOR LIGHT EMITTING DIODES

Technical Field

[1] The present invention relates to an apparatus for driving light emitting diodes and, more particularly, to a driving apparatus for light emitting diodes that can directly use AC voltage with minimized power consumption while enabling reduction of manufacturing costs.

Background Art

[2] In general, light emitting diodes (LEDs) have various advantages including low power consumption, semi-permanent lifespan and good brightness characteristics comparable to existing lighting devices, and considerable worldwide research has focused on taking advantage of such characteristics. Currently, LEDs are increasingly used as versatile lighting sources.

[3] LEDs are normally driven by a low current of dozens of mA. Hence, when LEDs are directly connected to an alternating current (AC) power source, as the current is not regulated, a small change in the AC power source may generate a large change in current and the LEDs may be easily damaged. To use AC voltage of 220 V to drive an LED, an AC-to-DC converter or the like is needed to convert AC voltage into low DC voltage. Such an additional circuit element becomes a major factor that makes the LED driving circuit more complex, causes extra power consumption, raises manufacturing costs and reduces overall efficiency.

[4] Accordingly, various schemes have been developed to drive LEDs using only passive elements. Among them, the simplest circuit capable of driving LEDs using an AC power source is a circuit using a resistor and a diode bridge to limit current.

[5] FIG. 1 illustrates an existing LED driving circuit using a rectifier. In the LED driving circuit of FIG. 1, an AC wave from an AC power source 11 is passed through a diode bridge 13 for rectification and the rectified wave is fed to an array of LEDs 15, which then radiate light. A series resistor 17 acts as a current limiting device. This circuit may drive LEDs with an AC power source using only passive elements without using an active element. However, as current flows through the series resistor, power is inevitably unnecessarily consumed by the resistor. When the temperature of the LEDs rises during light radiation, the forward voltage drop of the LEDs decreases and the current flowing through the LEDs increases. Hence, stability of brightness may be not maintained. In addition, when the input AC voltage is increased, the LED current is increased and stability of brightness may be not maintained.

[6] FIG. 2 illustrates an existing LED driving circuit that uses a series capacitor instead of a series resistor to limit current, and FIG. 3 shows the waveform of input current resulting from the circuit of FIG. 2. Use of a series capacitor 19 may prevent heat loss caused by a series resistor. However, in this case, if an appropriate operating point is not selected, the brightness of the LEDs may significantly change owing to changes in LED temperature and source voltage and the circuit may become useless owing to harmonics and power factor degradation caused by severe distortion of the input current waveform.

[7] Accordingly, to solve the above described problems of the existing LED driving circuits, it is necessary to make the LED brightness insensitive to changes in the LED temperature and source voltage.

Disclosure of Invention

Technical Problem

[8] The present invention has been made in view of the above problems, and the present invention provides an LED driving apparatus that employs a capacitor as a passive element and operates using an AC power source in a highly effective manner with low power loss so that LED brightness is insensitive to changes in temperature and source voltage and good characteristics are produced in relation to harmonics of input current and power factor.

[9] The present invention also provides an LED driving apparatus that operates using an AC power source and smoothes the current flowing through the LED array connected between both ends of a diode bridge of the circuit with a decrease in maximum current so as to prevent LED damage and keep the output of the LED array constant.

Solution to Problem

[10] An aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; and a first LED array and a second LED array connected in series with the capacitor, wherein the first LED array and the second LED array are connected in parallel and have opposite polarities, wherein the voltage drop of the LED arrays is one half the maximum voltage of the AC power source.

[11] Another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; an LED array connected in series with the capacitor; and a diode bridge connected with both ends of the AC power source and driving the LED array at a frequency two times higher than that of the AC power source, wherein the LED array is connected with both ends of the diode bridge and the voltage drop of the LED array is one half the maximum voltage of the AC power source.

[12] Still another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; an LED array connected in series with the capacitor; at least one surge absorber whose temperature changes according to the voltage magnitude of the AC power source; and at least one variable capacitor whose capacitance changes according to temperature changes of the surge absorber, wherein, when the AC voltage exceeds a rated voltage, the surge absorber connected in parallel with the AC power source generates heat and the capacitance of the variable capacitor decreases owing to the heat transferred from the surge absorber, thereby keeping the brightness of the LED array constant.

[13] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; an LED array connected with the capacitor in series; and at least one variable capacitor whose capacitance changes according to temperature changes of the LED array, wherein, when the temperature of the LED array rises owing to increase in the voltage of the AC power source, the capacitance of the variable capacitor is decreased to thereby keep the brightness of the LED array constant.

[14] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; an LED array connected in series with the capacitor; and at least one variable capacitor whose capacitance changes according to the voltage magnitude of the AC power source, wherein, when the voltage of the AC power source exceeds a rated voltage and the voltage across the variable capacitor increases, the capacitance of the variable capacitor is decreased to thereby maintain the brightness of the LED array constant.

[15] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: a capacitor generating a current whose phase leads that of the voltage of an AC power source; an inductor generating a current whose phase lags that of the voltage of the AC power source; and a first LED array connected in series with the capacitor and a second LED array connected in series with the inductor, wherein both the first LED array and the second LED are operated at a frequency two times higher than that of the AC power source.

[16] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; an LED array connected in series with the capacitor; and at least one variable capacitor whose capacitance changes according to changes in ambient temperature, wherein, when the brightness of the LED array decreases

according to rise in ambient temperature, the capacitance of the variable capacitor is increased to thereby keep the brightness of the LED array constant.

[17] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one capacitor connected in series with an AC power source to limit current; and an LED array connected in series with the capacitor, wherein the voltage drop of the LED array is set to a value exceeding one half of the maximum voltage of the AC power source, and the voltage drop of the LED array approaches one half the maximum voltage of the AC power source as ambient temperature rises, thereby keeping the brightness of the LED array constant.

[18] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: an LED array including a plurality of LEDs; and at least one switch connected in parallel with at least one LED of the LED array to turn on and off the at least one connected LED, wherein the switch turns on or off the at least one connected LED according to changes in ambient temperature and the maximum voltage of an AC power source, thereby keeping the brightness of the LED array constant.

[19] Yet another aspect of the present invention is to provide a driving apparatus for light emitting diodes (LEDs), including: at least one first capacitor connected in series with an AC power source to limit current; an LED array connected in series with the first capacitor; a diode bridge connected with both ends of the AC power source and driving the LED array at a frequency two times higher than that of the AC power source; and a second capacitor connected with both ends of the LED array to keep current flowing through the LED array constant.

Advantageous Effects of Invention

[20] In a feature of the present invention, an LED driving apparatus is provided that operates using an AC power source on the basis of a simple driving circuit. The LED driving apparatus is insensitive to changes in temperature and source voltage, may be manufactured at low costs, consumes only a small amount of power, has good characteristics in relation to harmonics of input current and power factor, and operates at a high frequency in a flicker-free way.

[21] In the LED driving apparatus using an AC power source, the current flowing through the LED array connected between both ends of a diode bridge is smoothed and maximum current is decreased at the same time. Hence, LED damage is prevented and the output of the LED array is kept constant, increasing LED lifetime.

Brief Description of Drawings

[22] The objects, features and advantages of the present invention will be more apparent from the following detailed description in conjunction with the accompanying

drawings, in which:

[23] FIG. 1 illustrates an existing LED driving circuit using a rectifier;

[24] FIG. 2 illustrates another existing LED driving circuit that uses a series capacitor to limit current instead of a series resistor of FIG. 1;

[25] FIG. 3 shows the waveform of input current resulting from the circuit of FIG. 2;

[26] FIG. 4 is a circuit diagram in which the LED array is reduced to an equivalent voltage source and resistor for power transfer analysis according to the present invention;

[27] FIG. 5 is a graph of voltage-current characteristics of a single LED;

[28] FIG. 6 depicts an input voltage, input current, output voltage, output current, voltages at both ends of the capacitor, and power consumed by the LED array when an AC voltage is applied to the circuit of FIG. 4 for one cycle;

[29] FIG. 7 is a circuit diagram equivalent to that of FIG. 4 when bridge diodes D1 and D4 are on and bridge diodes D2 and D3 are off;

[30] FIG. 8 is a circuit diagram equivalent to that of FIG. 4 when all bridge diodes D1, D2, D3 and D4 are off;

[31] FIG. 9 is a circuit diagram equivalent to that of FIG. 4 when bridge diodes D2 and D3 are on and bridge diodes D1 and D4 are off;

[32] FIG. 10 is a circuit diagram equivalent to that of FIG. 4 when all bridge diodes D1, D2, D3 and D4 are off;

[33] FIGS. 11 and 12 are graphs of power P with respect to V_m and nV_d in Math Figure 4;

[34] FIG. 13 is a graph of total illuminance measured while varying the number of LEDs;

[35] FIG. 14 illustrates a linear equation kt representing the input voltage from an AC power source of 220 V (rms) for computational simplification;

[36] FIG. 15 is a graph highlighting LED switching on the basis of Math Figure 10;

[37] FIG. 16 illustrates an LED driving circuit according to an embodiment of the present invention;

[38] FIG. 17 illustrates an LED driving circuit according to another embodiment of the present invention;

[39] FIG. 18 illustrates an LED driving circuit according to another embodiment of the present invention;

[40] FIG. 19 depicts the waveforms of measured input voltage v_s and input current i_s when the driving circuit of FIG. 4 is driven under the condition of $x = \frac{nV_d}{V_m} = 0.5$;

[41] FIG. 20 illustrates an LED driving circuit according to another embodiment of the

present invention;

[42] FIG. 21 illustrates an LED driving circuit according to another embodiment of the present invention;

[43] FIG. 22 illustrates an LED driving circuit according to another embodiment of the present invention;

[44] FIG. 23 illustrates an LED driving circuit according to another embodiment of the present invention;

[45] FIG. 24 depicts the waveforms of input voltage and input current in the circuit of FIG. 23;

[46] FIG. 25 illustrates an LED driving circuit according to another embodiment of the present invention;

[47] FIG. 26 illustrates an LED driving circuit according to another embodiment of the present invention;

[48] FIG. 27 depicts changes in the turn-on voltage V_d and illuminance of an LED according to changes in ambient temperature;

[49] FIG. 28 is a graph of power *P* consumed by the LED array with respect to the voltage drop nV_d thereof;

[50] FIG. 29 illustrates an LED array and switches of an LED driving circuit according to another embodiment of the present invention;

[51] FIG. 30 illustrates a circuit composed of a BJT, a resistor, a Zener diode and a capacitor to realize the feature provided in FIG. 29;

[52] FIG. 31 illustrates a capacitive LED driving circuit according to another embodiment of the present invention;

[53] FIG. 32 illustrates an inductive LED driving circuit according to another embodiment of the present invention;

[54] FIG. 33 is a circuit diagram derived from the LED driving circuit of FIG. 31 by replacing the array of n LEDs with an equivalent voltage source nV_d, resistor nr_d and ideal diode;

[55] FIG. 34 depicts the waveforms of the current and voltage through and across the LED array for one period T of an AC power source when a parallel capacitor C_2 is removed from the circuit of FIG. 33; and

[56] FIG. 35 depicts waveforms smoother than those of FIG. 34 when the parallel capacitor C_2 is used in the circuit of FIG. 33.

Mode for the Invention

[57] Hereinafter, exemplary embodiments of the present invention will be described with reference to the accompanying drawings. In particular, specific terms may be defined

to describe the invention in the best manner. Accordingly, the meaning of specific terms or words used in the specification and the claims should not be limited to the literal or commonly employed sense, but should be construed in accordance with the spirit of the invention. The description of the various embodiments is to be construed as exemplary only and does not describe every possible instance of the invention. Therefore, it should be understood that various changes may be made and equivalents may be substituted for elements of the invention.

[58] FIG. 4 is a circuit diagram in which the LED array is reduced to an equivalent voltage source and a resistor for power transfer analysis according to the present invention.

[59] As shown in FIG. 4, to analyze power transfer characteristics when a current limiting capacitor is used, the LED array is reduced to an equivalent voltage source and resistor. The voltage of the AC power source is denoted by v_s, the voltage across the capacitor is denoted by v_c, the input voltage to the diode bridge is denoted by v_b. When the forward voltage drop of one LED is assumed to be V_d, the voltage v_o across the array of n LEDs is given by $n V_d$. The input current is denoted by i_s, and the LED current at the output terminal is denoted by i_o.

[60] FIG. 5 is a graph of voltage-current characteristics of a single LED, and indicates that the characteristics may be approximated by an equivalent voltage source and resistor.

[61] Referring to FIG. 5, the voltage equation for the internal loop of the circuit may be represented by Math Figure 1.

[62] MathFigure 1

[Math.1]

$$v_s = v_c + v_b = V_m \sin(\omega t)$$

[63] FIG. 6 depicts an input voltage, input current, output voltage, output current, voltages at both ends of the capacitor, and power consumed by the LED array when an AC voltage is applied to the circuit of FIG. 4 for one cycle.

[64] In FIG. 6, when an AC voltage is applied to the circuit of FIG. 4 for one cycle, the input voltage is denoted by

v_s

, the input current is denoted by

i_s

, the output voltage is denoted by

v_o

, the output current is denoted by

i_o

, voltages at both ends of the capacitor are denoted by

v_c

and

v_b

, and the power consumed by the LED array is denoted by *P*.

[65] To examine important characteristics of the circuit, first it is assumed that

$r_d = 0$

and the bridge diodes and input voltage are ideal. Other cases are handled separately below.

[66] FIG. 7 is a circuit diagram equivalent to that of FIG. 4 when bridge diodes D1 and D4 are on and bridge diodes D2 and D3 are off.

[67] The circuit of FIG. 7 is equivalent to that of FIG. 4 when the bridge diodes D1 and D4 are on and the bridge diodes D2 and D3 are off. This case corresponds to interval A in FIG. 6, where the input voltage

v_s

, the input current

i_s

, the voltage

v_c

across the capacitor, the voltage

v_b

input to the bridge diodes and the power *P* consumed by the LED array are plotted. In this case, the current flowing through the circuit is determined by the input voltage, and is given by Math Figure 2.

[68] MathFigure 2

[Math.2]

$$i_s = C\frac{dv_c}{dt} = C\frac{d(v_s - nV_d)}{dt} = C\frac{dv_s}{dt} = \omega C V_m \cos(\omega t) = I_m \cos(\omega t)$$

[69] Interval A lasts while the current flowing through the capacitor is positive and ends when the current becomes zero as the input voltage reaches maximum.

[70] FIG. 8 is a circuit diagram equivalent to that of FIG. 4 when all bridge diodes D1, D2, D3 and D4 are off.

[71] The case of FIG. 8 corresponds to interval B in FIG. 6, where the input voltage

v_s

, the input current
i_s
, the voltages at both ends of the capacitor
v_b
and
v_c
, and the power P consumed by the LED array are plotted.

[72] Interval B lasts while the input voltage to the bridge diodes decreases from
nV_d
and
$-nV_d$
reaches in FIG. 4 and ends when the input voltage falls by
$2nV_d$
.

[73] FIG. 9 is a circuit diagram equivalent to that of FIG. 4 when the bridge diodes D2 and D3 are on and the bridge diodes D1 and D4 are off.

[74] The case of FIG. 9 corresponds to interval C in FIG. 6, where the input voltage
v_s
, the input current
i_s
, the voltages at both ends of the capacitor
v_b
and
v_c
, and the power P consumed by the LED array are plotted. In this case also, the current flowing through the circuit is determined by the input voltage, and is given by Math Figure 3.

[75] MathFigure 3
[Math.3]

$$i_s = C\frac{dv_c}{dt} = C\frac{d(v_s + nV_d)}{dt} = C\frac{dv_s}{dt} = \omega CV_m \cos(\omega t) = I_m \cos(\omega t)$$

[76] Interval C lasts while the current flowing through the capacitor is negative and ends when the current becomes zero as the input voltage reaches minimum.

[77] FIG. 10 is a circuit diagram equivalent to that of FIG. 4 when all bridge diodes D1, D2, D3 and D4 are off.

[78] The case of FIG. 10 corresponds to interval Din FIG. 6, where the input voltage

v_s

, the input current

i_s

, the voltages at both ends of the capacitor

v_b

and

v_c

, and the power *P* consumed by the LED array are plotted.

[79] Interval D lasts while the input voltage to the bridge diodes rises from

$-nV_d$

and reaches

nV_d

in FIG. 4 and ends when the input voltage rises by

$2nV_d$

.

[80] In FIG. 4, the average power consumed by the LED array during one cycle of the AC power source may be computed using Math Figure 4.

[81] MathFigure 4

[Math.4]

$$P = nV_d\overline{i_o(t)}$$

$$= nV_d\frac{1}{T}\int_0^T i_o(t)dt$$

$$= nV_d\frac{1}{T}\int_0^T |i_s(t)|dt$$

$$= nV_d\frac{2}{T}\int_{\frac{T}{4}+\frac{\theta}{w}}^{\frac{3T}{4}} |I_m\cos\omega t|dt$$

$$= \frac{nV_d}{\pi}\int_{\frac{\pi}{2}+\theta}^{\frac{3\pi}{2}} |I_m\cos\phi|d\phi, \quad \because \phi = \omega t$$

$$= \frac{nV_dI_m}{\pi}\left\{-\sin\frac{3\pi}{2}+\sin(\frac{\pi}{2}+\theta)\right\}$$

[82]
$$= \frac{nV_dI_m}{\pi}(1+\cos\theta)$$
$$= \frac{nV_dI_m}{\pi}(1+\frac{V_m-2nV_d}{V_m}), \because V_m\cos\theta = V_m - 2nV_d$$
$$= \frac{2\omega C}{\pi}nV_d(V_m - nV_d), \because I_m = \omega CV_m$$
$$= \frac{2\omega CV_m{}^2}{\pi}x(1-x), \because x \equiv nV_d/V_m$$

[83] FIGS. 11 and 12 are graphs of power P with respect to V_m and nV_d in Math Figure 4.

[84] As described, the power consumed by the LED arrayis parabolically related to nV_d and reaches maximum as given by Math Figure 5 when $x = \frac{nV_d}{V_m} = 0.5$.

[85] MathFigure 5

[Math.5]

$$P_m = \frac{2\omega CV_m{}^2}{\pi}x(1-x)|_{x=0.5} = \frac{\omega CV_m{}^2}{2\pi} = \frac{\omega CV_s{}^2}{\pi}, \quad \because V_m = \sqrt{2}\,V_s$$

[86] More importantly, even though V_d varies owing to heat generated by the LED or ambient temperature, P_m does not significantly change so long as x remains at about 0.5. For example, when V_d varies by ±10 percent,

P_m

varies only by ±1 percent. However, this property does not hold when

x

becomes too small or large (0.2 or 0.8) in comparison to 0.5.

[87] As shown in FIG. 6, when

$x = \frac{nV_d}{V_m} = 0.5$

, the input current starts to flow at a point where the input voltage is 0. This point can be obtained using Math Figure 6.

[88] MathFigure 6

[Math.6]

$$\cos\theta = (V_m - 2nV_d)/V_m|_{x = nV_d/V_m = 0.5} = 0 \quad \Rightarrow \theta = \frac{\pi}{2}$$

[89] When

x

is less than 0.5, reactive power is generated because there exists a duration where polarities of the input voltage and input current are opposite. When

x

is greater than 0.5, the time during which the current flows becomes shorter and the maximum current is increased in order to transfer the same power to the LED, increasing Ohmic loss.

[90] In summary, only when

$x = \frac{nV_d}{V_m} = 0.5$

, the LED brightness may be insensitive to changes in temperature, and good power factor and maximum efficiency can be obtained. To achieve this, it suffices to determine the number of LEDs as in Math Figure 7.

[91] MathFigure 7

[Math.7]

$$n = 0.5\frac{V_m}{V_d} = 0.5\frac{311}{3} = 51.8 \cong 52, \quad \because V_d = 3[V], \; V_m = 220\sqrt{2} = 311[V]$$

[92] FIG. 13 is a graph of total illuminance measured while varying the number of LEDs.

[93] As shown in FIG. 13, when the number of LEDs is between 40 and 70, a difference in illuminance discernible to the human eye does not occur. The same is true when the LED forward voltage changes owing to temperature variation. When the number of LEDs is too small, harmonics are generated in the input current as in FIG. 3 and power

factor is small. This may cause serious EMI/EMC problems in power lines when LED lighting appliances become popular and hence is undesirable.

[94] Next, switching noise that is generated by on-off operation of LEDs directly connected to an AC power source is analyzed in detail. In the case of

$$x = \frac{nV_d}{V_m} = 0.5$$

, the LED starts to be turned on when the input voltage becomes 0 as in Math Figure 6. When

x

is not exactly 0.5, the LED is turned on when the input voltage is not 0. However, when

x

does not differ too much from 0.5 as in Math Figure 9, as

k

does not change significantly, the results of the following Math Figures are still effective without much differences.

[95] Here, the input voltage may be represented by Math Figure 8.

[96] MathFigure 8

[Math.8]

$$v_s = v_c + v_d \cong \omega V_m t = kt \quad \because v_s = V_m \sin\omega t \cong V_m \omega t, \ \omega t \ll \frac{\pi}{2} \quad \Rightarrow \quad k \equiv \omega V_m$$

[97] FIG. 14 illustrates a linear equation

kt

representing the input voltage from an AC power source of 220 V (rms) for computational simplification.

[98] Using the linear equation of FIG. 14, the equality between the current flowing through the LED and the current flowing through the capacitor, and Math Figure 8, one can derive Math Figure 9 below. Here, the LED is assumed to have characteristics of a realistic (not ideal) diode as shown FIG. 5.

[99] MathFigure 9

[Math.9]

$$i_s = C\frac{dv_c}{dt} = i_o = I_o\left(e^{\frac{v_d}{V_T}} - 1\right) \cong I_o e^{\frac{v_d}{V_T}}$$

$$\rightarrow C\frac{dv_c}{dt} = C\frac{d}{dt}(kt - v_d) = C\left(k - \frac{dv_d}{dt}\right) = I_o e^{\frac{v_d}{V_T}}$$

[100] The solution of the differential equation given in Math Figure 9 is provided in Math Figure 10.

[101] MathFigure 10
[Math.10]

$$i_o = \frac{Ck}{1+\left(\frac{Ck}{I_o}e^{-\frac{nV_T}{V_T}}-1\right)e^{-\frac{kt}{V_T}}} \cong I_o e^{\frac{nV_T+kt}{V_T}},\ t \ll \frac{T}{10}$$

[102] FIG. 15 is a graph highlighting LED switching on the basis of Math Figure 10.

[103] As shown in FIG. 15, the LED current does not abruptly increase upon switching and, instead, slowly increases at the beginning and exponentially increases later according to diode voltage-current characteristics described by Math Figure 10. Consequently, the current flowing through the LED is influenced by the current flowing through the series capacitor, and an actual graph thereof for one fourth of the period is shown in FIG. 15.

[104] As described above, under the condition of

$x = \frac{nV_d}{V_m} = 0.5$

, the current gradually changes upon LED switching and generation of serious harmonics in the input current is suppressed.

[105] FIG. 16 illustrates an LED driving circuit according to an embodiment of the present invention.

[106] Referring to FIG. 16, the driving circuit includes an AC power source 31 for supplying power, at least one capacitor 33, and two or more arrays of LEDs 35 for light radiation. The capacitor 33 is connected in series with the AC power source 31 and limits current. The parallel LED arrays 35 are connected to the capacitor 33, and the LEDs of one LED array 35 are in a direction (with respect to a pair of anode and cathode) opposite to those of another LED array 35. The LED arrays 35 emit light alternately according to AC signals. Here, when the total voltage drop of the LED arrays 35 is denoted by

nV_d

(

V_d

is the turn-on voltage of an LED) and the maximum voltage of the AC power source 31 is denoted by

V_m

, the relationship

$nV_d = \frac{V_m}{2}$

substantially holds. As a result, the brightness and efficiency of the LED arrays 35 are maximized; the influence of temperature changes is minimized; and ideal characteristics related to harmonics in the input current and power factor are achieved.

[107] FIG. 17 illustrates an LED driving circuit according to another embodiment of the present invention.

[108] Referring to FIG. 17, the driving circuit includes an AC power source 41 supplying power, at least one capacitor 43, a diode bridge 45 for rectification, and at least one LED array 47 for light radiation. The capacitor 43 is connected in series with the AC power source 41 and limits current. The diode bridge 45 is connected with both ends of the AC power source 41 and drives the LED array 47at two times the frequency of the AC power source 41. The LED array 47 is connected with both ends of the diode bridge 45 and is connected in series with the AC power source 41 and the capacitor 43. Here, when the total voltage drop of the LED array 47 is denoted by

nV_d

and the maximum voltage of the AC power source is denoted by

V_m

, the relationship

$nV_d = \frac{V_m}{2}$

substantially holds. As a result, the brightness and efficiency of the LED array 47 are maximized; the influence of temperature changes is minimized; and ideal characteristics related to harmonics in the input current and power factor are achieved.

[109] FIG. 18 illustrates an LED driving circuit according to another embodiment of the present invention.

[110] Referring to FIG. 18, the driving circuit includes an AC power source 51 supplying power, at least one capacitor 53, a diode bridge 55 for rectification, and at least one LED array 57 for light radiation. The circuit of FIG. 18 is similar to that of FIG. 17, but the diode bridge 55 includes LEDs to increase efficiency of light radiation. To use a commercial power source, the diode bridge 55 is normally composed of five to ten LEDs because an LED has a reverse withstand voltage of less than or equal to 30 V.

[111] FIG. 19 depicts the waveforms of measured input voltage

v_s

and input current

i_s

when the driving circuit of FIG. 4 is driven under the condition of

$x = \frac{nV_d}{V_m} = 0.5$

.

[112] FIG. 19 indicates that, although the waveform of the input current

i_s

includes some harmonics caused by line inductance and line parasitic capacitance, the input current waveform conforms well to the theoretical result of FIG. 15 and the harmonics are weak and negligible in practice.

[113] FIG. 20 illustrates an LED driving circuit according to another embodiment of the present invention.

[114] Referring to FIG. 20, the driving circuit includes an AC power source 61 supplying power, at least one capacitor 65 for limiting current, a surge absorber 63, at least one variable capacitor 67 whose capacitance varies according to temperature changes, and at least one LED array 69 for light radiation. The LED array 69 may have any of the configurations provided in FIGS. 16 to 18. The variable capacitor 67 is connected with the current-limiting capacitor 65 in parallel or in series. The surge absorber 63 is connected with the AC power source 61 in parallel. When the AC voltage exceeds the rated voltage, the surge absorber 63 generates a small amount of heat and the heat is transferred to the variable capacitor 67 and reduces the capacitance thereof, keeping the brightness of the LED array 69 constant. That is, when the maximum source voltage

V_m

exceeds the rated voltage, the surge absorber 63 radiates heat and the capacitance of the variable capacitor 67 is decreased owing to the heat from the surge absorber 63. Referring to Math Figure 5, the power consumed by the LED is proportional to the square of

V_m

, and hence it is possible to keep the LED output constant by reducing capacitance accordingly. In this case, the circuit does not need to be driven exactly with

$x = \frac{nV_d}{V_m} = 0.5$

, and the circuit may be intentionally driven with a smaller or larger value of

x

.

[115] FIG. 21 illustrates an LED driving circuit according to another embodiment of the present invention.

[116] Referring to FIG. 21, the driving circuit includes an AC power source 71 supplying power, at least one capacitor 73 for limiting current, at least one LED array 75 for light radiation, and at least one variable capacitor 77 whose capacitance varies according to temperature changes of the LED array 75. The LED array 75 may have any of the configurations provided in FIGS. 16 to 18. The variable capacitor 77 is connected in parallel or series with the current-limiting capacitor 73 and is connected in series with

the AC power source 71 and the LED array 75. Since the variable capacitor 77 is thermally coupled with the LED array 75, when the LED array 75 is heated owing to rise in the source voltage, the capacitance of the variable capacitor 77 is decreased and the brightness of the LED array 75 is maintained constant. That is, the capacitance of the variable capacitor 77 changes owing to heat generated by the LED array 75. Since the power consumed by the LED array 75 is proportional to the square of

V_m

, the temperature thereof may rise. Hence, it is possible to maintain the brightness of the LED array 75 constant by changing the capacitance of the variable capacitor 77 accordingly. If the circuit is driven at

$x = \frac{n V_d}{V_m} = 0.5$

, the brightness of the LED array 75 is kept constant according to changes in the LED forward voltage caused by changes in LED temperature. However, the circuit is not necessarily driven at this operating point.

[117] FIG. 22 illustrates an LED driving circuit according to another embodiment of the present invention.

[118] Referring to FIG. 22, the driving circuit includes an AC power source 81 supplying power, at least one capacitor 83 for limiting current, at least one variable capacitor 85 whose capacitance varies according to voltage, and at least one LED array 87 for light radiation. The LED array 87 may have any of the configurations provided in FIGS. 16 to 18. The variable capacitor 85 is connected with the current-limiting capacitor 83 in parallel or series and is connected with the AC power source 81 and the LED array 87 in series. When the voltage of the AC power source 81 increases, the voltage across the variable capacitor 85 increases and the capacitance thereof decreases. Hence, the brightness of the LED array 87 is maintained constant. That is, the capacitance of the variable capacitor 85 is changed in inverse proportion to the voltage of the AC power source 81. When the AC voltage exceeds the rated voltage, the voltage across the variable capacitor 85 increases and the capacitance thereof decreases. This helps to keep the brightness of the LED array 87 constant.

[119] FIG. 23 illustrates an LED driving circuit according to another embodiment of the present invention, and FIG. 24 depicts the waveforms of input voltage and input current in the circuit of FIG. 23.

[120] Referring to FIG. 23, the driving circuit includes an AC power source 91 supplying power, at least one inductor 93 for limiting current, and at least one LED array 95 for light radiation. The LED array 95 may have any of the configurations provided in FIGS. 16 to 18. The inductor 93 is connected in series with the AC power source 91 and the LED array 95. The inductor 93 replaces the capacitor in the AC LED circuit of

FIG. 4. While the input current wave in the circuit of FIG. 4 using a capacitor leads the input voltage wave as illustrated in FIG. 19, the input current wave in the circuit of FIG. 23 using an inductor lags behind the input voltage wave as illustrated in FIG. 24. Utilization of an inductor produces effects similar to utilization of a capacitor.

[121] FIG. 25 illustrates an LED driving circuit according to another embodiment of the present invention.

[122] Referring to FIG. 25, the driving circuit includes an AC power source 101 supplying power, at least one inductor 103 and at least one capacitor 105 for limiting current, and two or more LED arrays 107 and 109 for light radiation. Each of the LED arrays 107 and 109 may have any of the configurations provided in FIGS. 16 to 18. The inductor 103 is connected in series with the AC power source 101 and the LED array 109, and the capacitor 105 is connected in series with the AC power source 101 and the LED array 107 being not connected to the inductor 103. Here, in the path involving the inductor 103, the input current lags behind the voltage of the AC power source 101; and in the path involving the capacitor 105, the input current leads the voltage of the AC power source 101. Hence, the overall circuit is preferably driven at a frequency four times higher than that of the AC power source 101. The overall circuit in FIG. 25 is composed of the LED driving circuit using a capacitor in FIG. 4 and the LED driving circuit using an inductor in FIG. 4. The LED driving circuit in FIG. 25 generates both effects of leading current by the capacitor 105 and effects of lagging current by the inductor 103 and hence can operate the LED arrays at a frequency four times higher than that of the AC power source. Simultaneous use of two LED arrays may significantly reduce flickering caused by an AC power source.

[123] FIG. 26 illustrates an LED driving circuit according to another embodiment of the present invention, and FIG. 27 depicts changes in the turn-on voltage

V_d

and illuminance of an LED according to changes in ambient temperature.

[124] Referring to FIG. 26, the driving circuit includes an AC power source 111 supplying power, at least one capacitor 113 for limiting current, at least one variable capacitor 115 whose capacitance varies according to ambient temperature T, and at least one LED array 117 for light radiation. The LED array 117 may have any of the configurations provided in FIGS. 16 to 18. The variable capacitor 115 is connected in parallel or series with the current-limiting capacitor 113 and is connected in series with the AC power source 111 and the LED array 117. As shown in FIG. 27, the turn-on voltage

V_d

and illuminance

$\eta(T)$

of an LED decrease according to rise in ambient temperature T. This is detrimental to LED driving. In the LED driving circuit of FIG. 26, the capacitance of the variable capacitor 115 is increased according to ambient temperature T, cancelling variations in the brightness of the LED array 117. That is, when the brightness of the LED array 117 decreases according to rise in ambient temperature T, the capacitance of the variable capacitor 115 is increased to thereby keep the brightness of the LED array 117 constant.

[125] FIG. 28 is a graph of power *P* consumed by the LED array with respect to the voltage drop nV_d thereof.

[126] Referring to FIG. 28, after the operating point of an AC LED driving circuit is placed at a point V_2 where the voltage drop nV_d of the LED array is greater than half of the maximum AC voltage V_m, as the ambient temperature rises, the voltage drop nV_d of the LED array changes from V_2 to V_1 and the power *P* consumed by the LED array changes from P_2 to P_1. This cancels the brightness change caused by a rise in temperature shown in FIG. 27, keeping the brightness of the LED array constant. That is, the voltage drop nV_d of the LED array is set to be greater than half the maximum AC voltage V_m. As described before, the voltage drop nV_d and illuminance $\eta(T)$ of the LED array decrease as the ambient temperature T rises. Hence, when the ambient temperature T rises, the voltage drop nV_d of the LED array approaches half the maximum AC voltage V_m and the brightness of the LED array is kept constant in spite of temperature changes.

[127] FIG. 29 illustrates an LED array and switches of an LED driving circuit according to another embodiment of the present invention.

[128] Referring to FIG. 29, switches sw(1) to sw(m) of a switch array 123 are respectively connected in parallel with associated LEDs 121, and each of the switches sw(1) to sw(m) turns on and off the associated LED 121 according to changes in temperature T and maximum AC voltage

V_m

. When the overall brightness of the array of LEDs 121 changes according to changes in temperature T and maximum AC voltage

V_m

, the switches sw(1) to sw(m) of the switch array 123 individually turn on or off the associated LEDs 121, thereby keeping the overall brightness of the array of LEDs 121 constant.

[129] FIG. 30 illustrates a circuit composed of a BJT, a resistor, a Zener diode and a capacitor to realize the features provided in FIG. 29. The circuit of FIG. 30 is purely an example of the circuit portion of FIG. 29. The BJT and passive elements used in FIG. 30 may be replaced with other elements including MOS devices.

[130] The voltage drop of an LED increases according to decrease in temperature T as depicted in FIG. 27. Referring to FIG. 30, when an increase in the voltage drop of an LED exceeds the voltage V_Z of a Zener diode 131, the Zener diode 131 is turned on to thereby increase the base voltage of an NPN transistor 133. Then, the collector voltage of the NPN transistor 133 falls to thereby lower the base voltage of a PNP transistor 135 connected with the collector of the NPN transistor 133. Upon lowering the base voltage of the PNP transistor 135, the PNP transistor 135 is turned on. Hence, the current flows through the PNP transistor 135 while bypassing the m LEDs connected in parallel with the PNP transistor 135. As a result, the m LEDs are turned off and the voltage drop

nV_d

of the entire LED array is decreased by

mV_d

, keeping the brightness of the entire LED array constant in spite of changes in temperature T.

[131] The embodiments of the present invention described hereinabove are not limited to single phase power sources, but are applicable to three or two phase power sources. The LED used in the various embodiments is based on the phenomenon of electro luminescence (EL), which is applicable to organic and inorganic devices. An LED is an inorganic EL device, and an organic light emitting diode (OLED) is an organic EL device.

[132] FIG. 31 illustrates a capacitive LED driving circuit according to another embodiment

of the present invention; FIG. 32 illustrates an inductive LED driving circuit according to another embodiment of the present invention; FIG. 33 is a circuit diagram derived from the LED driving circuit of FIG. 31 by replacing the array of n LEDs with an equivalent voltage source nV_d, resistor nr_d and ideal diode; FIG. 34 depicts the waveforms of the current and voltage through and across the LED array for one period T of an AC power source when a parallel capacitor C_2 is removed from the circuit of FIG. 33; and FIG. 35 depicts waveforms smoother than those of FIG. 34 when the parallel capacitor C_2 is used in the circuit of FIG. 33.

[133] Referring to FIG. 31, the capacitive driving circuit includes an AC power source 141 supplying power, at least one capacitor 143, a diode bridge 145 for rectification, at least one LED array 147 for light radiation, and a parallel capacitor 149. The capacitor 143 is connected in series with the AC power source 141 and limits current. The diode bridge 145 is connected with both ends of the AC power source 141 and drives the LED array 147at two times the frequency of the AC power source 141. The LED array 147 is connected with both ends of the diode bridge 145 and is connected in series with the AC power source 141 and the capacitor 143. Particularly, in the capacitive LED driving circuit using AC power, the parallel capacitor 149 is connected in parallel with the LED array 147 to keep the current flowing through the LED array 147 constant. Such a parallel capacitor 149 may also be used in the inductive LED driving circuit as shown in FIG. 32. The inductive LED driving circuit is similar to the capacitive LED driving circuit, and a detailed description thereof is omitted.

[134] The circuit diagram of FIG. 33 is derived from the LED driving circuit of FIG. 31 by replacing the array 147 of n LEDs with an equivalent voltage source nV_d, resistor nr_d and ideal diode. The diode bridge 145 is assumed to be ideal, and the parallel capacitor 149 maintaining the output of the LED array 147 constant is assumed to have a capacitance C_2. When the parallel capacitor C_2 is absent, waveforms of the current and voltage through and across the LED array 147 for one period T of the AC power source 141 are shown in FIG. 34.

[135] The time constant of the equivalent resistor nr_d and the parallel capacitor C_2 is given by Math Figure 11.

[136] MathFigure 11

[Math.11]

$$\tau = nr_d \cdot C_2$$

[137] Using Math Figure 11, when C_2 is set to a value at which the time constant becomes greater than half the period (T/2) of the AC power, the charge stored in the capacitor C_2 flows to the LED array 147 even during an interval from t_1 to t_2 and another interval from t_3 to t_4 (in FIG. 34, no current flows during these intervals), and hence smoother

voltage and current waveforms may be obtained as shown in FIG. 35. The capacitor reduces fluctuations in the current flowing through the LED array 147 connected with both ends of the diode bridge 145 and decreases the maximum current flowing through the LED array 147 from i_{peak} to i'_{peak}. This prevents damage of the LED array 147 caused by overcurrent and keeps the output of the LED array 147 constant, increasing LED lifespan.

[138] While this invention has been described with reference to exemplary embodiments thereof, it will be clear to those of ordinary skill in the art to which the invention pertains that various modifications may be made to the described embodiments without departing from the spirit and scope of the invention as defined in the appended claims and their equivalents.

Claims

[Claim 1] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current; and
a first LED array and a second LED array connected in series with the capacitor, wherein the first LED array and the second LED array are connected in parallel and have opposite polarities,
wherein the voltage drop of the LED arrays is one half the maximum voltage of the AC power source.

[Claim 2] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current;
an LED array connected in series with the capacitor; and
a diode bridge connected with both ends of the AC power source and driving the LED array at a frequency two times higher than that of the AC power source,
wherein the LED array is connected with both ends of the diode bridge and the voltage drop of the LED array is one half the maximum voltage of the AC power source.

[Claim 3] The driving apparatus of claim 2, wherein the diode bridge is composed of one or more LEDs.

[Claim 4] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current;
an LED array connected in series with the capacitor;
at least one surge absorber whose temperature changes according to the voltage magnitude of the AC power source; and
at least one variable capacitor whose capacitance changes according to temperature changes of the surge absorber,
wherein, when the AC voltage exceeds a rated voltage, the surge absorber connected in parallel with the AC power source generates heat and the capacitance of the variable capacitor decreases owing to the heat transferred from the surge absorber, thereby keeping the brightness of the LED array constant.

[Claim 5] The driving apparatus of claim 4, wherein the voltage drop of the LED array is one half the maximum voltage of the AC power source.

[Claim 6] The driving apparatus of claim 4, wherein the variable capacitor is connected with the capacitor limiting current in parallel or in series.

[Claim 7] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current;
an LED array connected with the capacitor in series; and
at least one variable capacitor whose capacitance changes according to temperature changes of the LED array,
wherein, when the temperature of the LED array rises owing to increase in the voltage of the AC power source, the capacitance of the variable capacitor is decreased to thereby keep the brightness of the LED array constant.

[Claim 8] The driving apparatus of claim 7, wherein the voltage drop of the LED array is one half the maximum voltage of the AC power source.

[Claim 9] The driving apparatus of claim 7, wherein the variable capacitor is connected with the capacitor limiting current in parallel or in series.

[Claim 10] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current;
an LED array connected in series with the capacitor; and
at least one variable capacitor whose capacitance changes according to the voltage magnitude of the AC power source,
wherein, when the voltage of the AC power source exceeds a rated voltage and the voltage across the variable capacitor increases, the capacitance of the variable capacitor is decreased to thereby maintain the brightness of the LED array constant.

[Claim 11] The driving apparatus of claim 10, wherein the variable capacitor is connected in parallel with or in series with the capacitor limiting current.

[Claim 12] A driving apparatus for light emitting diodes (LEDs), comprising:
a capacitor generating a current whose phase leads that of the voltage of an AC power source;
an inductor generating a current whose phase lags that of the voltage of the AC power source; and
a first LED array connected in series with the capacitor and a second LED array connected in series with the inductor,
wherein both the first LED array and the second LED are operated at a frequency two times higher than that of the AC power source.

[Claim 13] A driving apparatus for light emitting diodes (LEDs), comprising:

at least one capacitor connected in series with an AC power source to limit current;
an LED array connected in series with the capacitor; and
at least one variable capacitor whose capacitance changes according to changes in ambient temperature,
wherein, when the brightness of the LED array decreases according to rise in ambient temperature, the capacitance of the variable capacitor is increased to thereby keep the brightness of the LED array constant.

[Claim 14] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one capacitor connected in series with an AC power source to limit current; and
an LED array connected in series with the capacitor,
wherein the voltage drop of the LED array is set to a value exceeding one half of the maximum voltage of the AC power source, and the voltage drop of the LED array approaches one half the maximum voltage of the AC power source as ambient temperature rises, thereby keeping the brightness of the LED array constant.

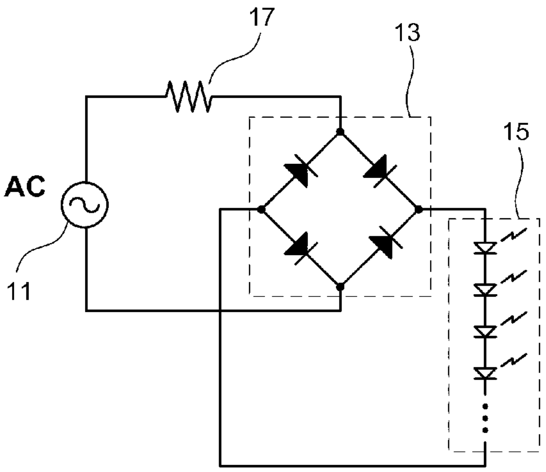
[Claim 15] A driving apparatus for light emitting diodes (LEDs), comprising:
an LED array including a plurality of LEDs; and
at least one switch connected in parallel with at least one LED of the LED array to turn on and off the at least one connected LED,
wherein the switch turns on or off the at least one connected LED according to changes in ambient temperature and the maximum voltage of an AC power source, thereby keeping the brightness of the LED array constant.

[Claim 16] A driving apparatus for light emitting diodes (LEDs), comprising:
at least one first capacitor connected in series with an AC power source to limit current;
an LED array connected in series with the first capacitor;
a diode bridge connected with both ends of the AC power source and driving the LED array at a frequency two times higher than that of the AC power source; and
a second capacitor connected with both ends of the LED array to keep current flowing through the LED array constant.

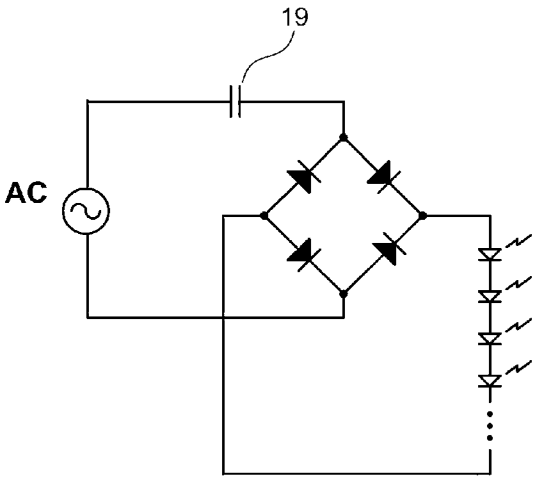
[Claim 17] The driving apparatus of claim 16, wherein the second capacitor is connected in parallel with the LED array.

[Claim 18] The driving apparatus of claim 16, wherein the second capacitor reduces changes in the current flowing through the LED array and decreases the maximum current flowing through the LED array to thereby keep the output of the LED array constant.

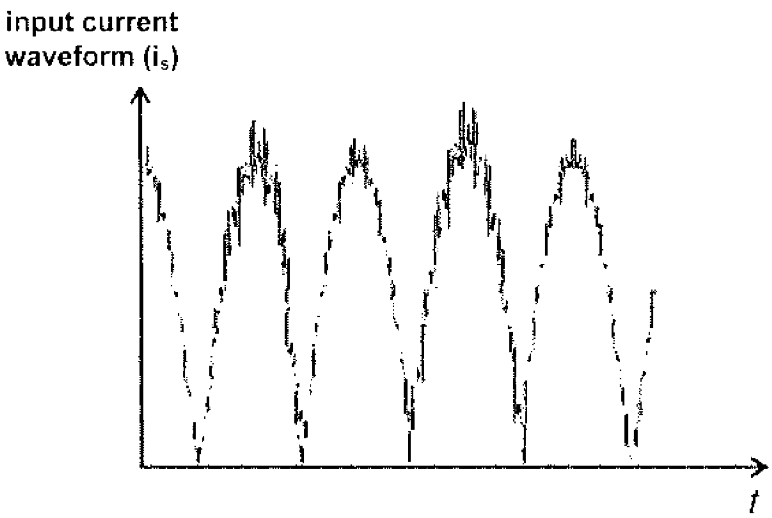
[Fig. 1]



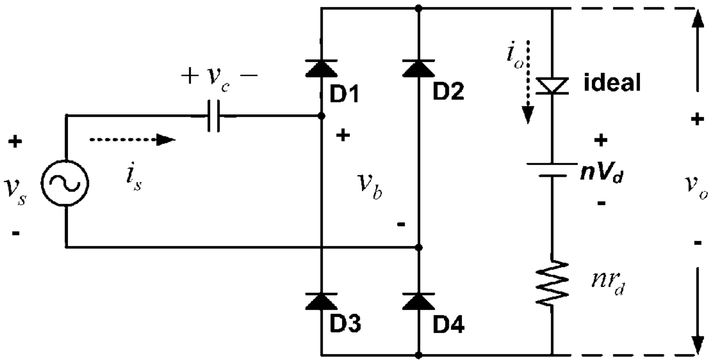
[Fig. 2]



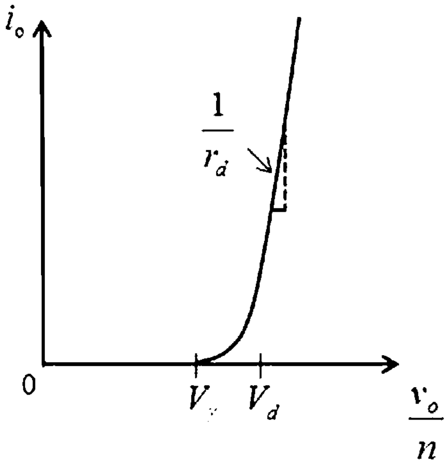
[Fig. 3]



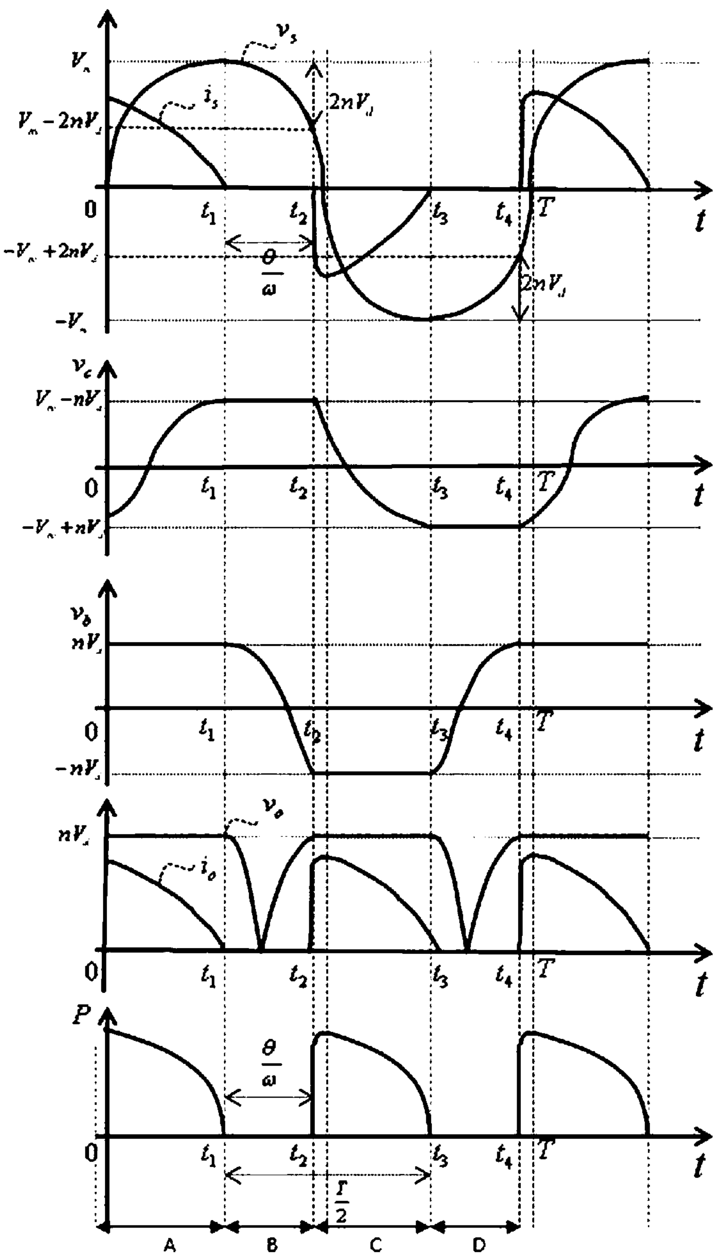
[Fig. 4]


$+ v_c -$
D1
D2
i_o
ideal
+
v_s
-
i_s
+
v_b
-
+
nV_d
-
+
v_o
-
nr_d
D3
D4

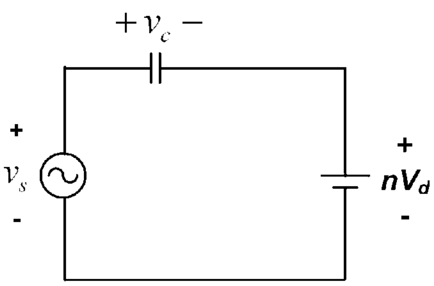
[Fig. 5]


i_o
$\frac{1}{r_d}$
0
V_γ
V_d
$\frac{v_o}{n}$

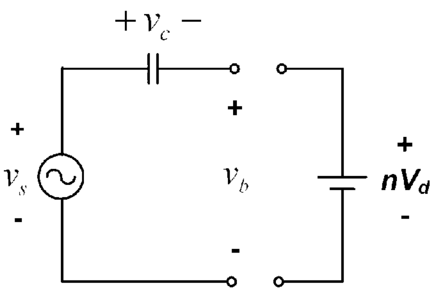
[Fig. 6]



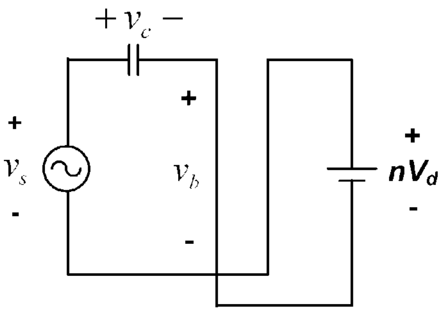
[Fig. 7]



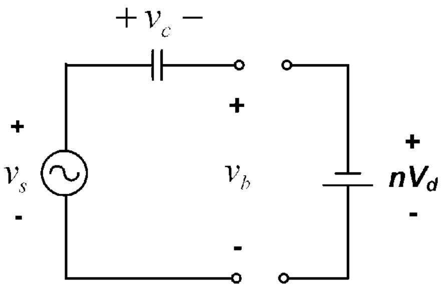
[Fig. 8]



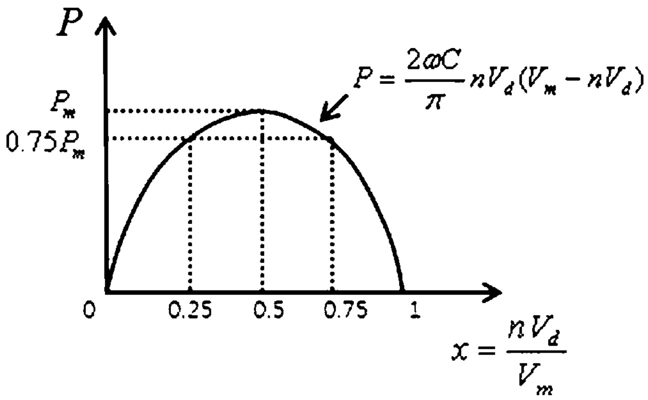
[Fig. 9]



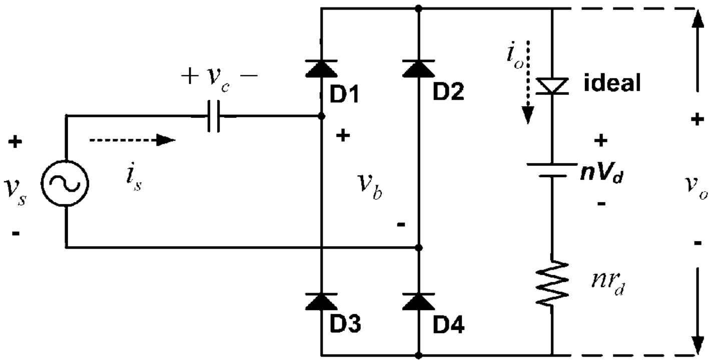
[Fig. 10]



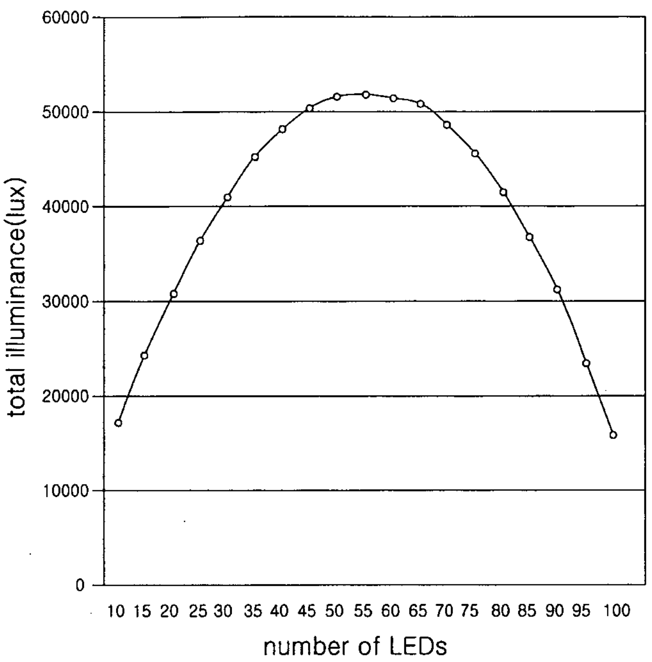
[Fig. 11]



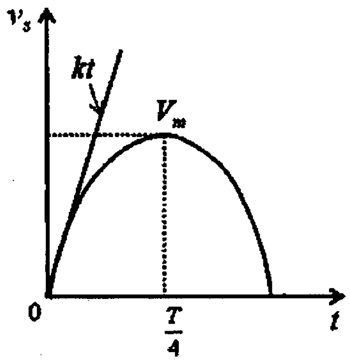
[Fig. 12]



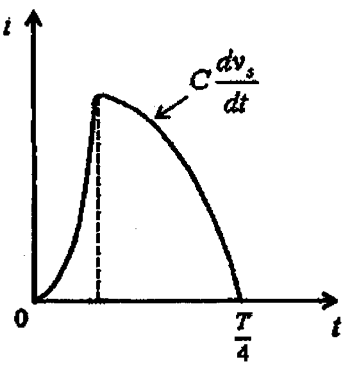
[Fig. 13]



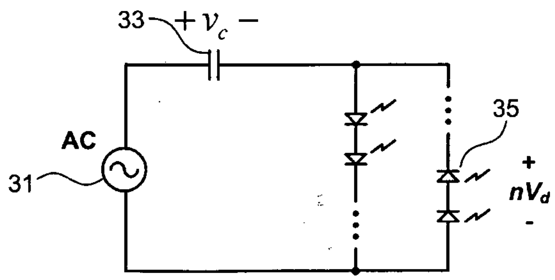
[Fig. 14]



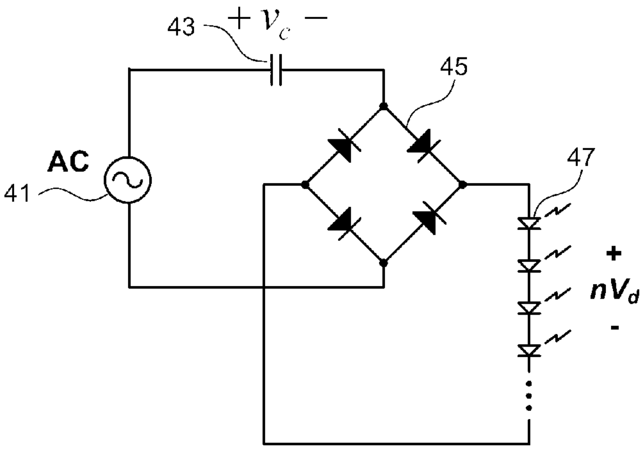
[Fig. 15]



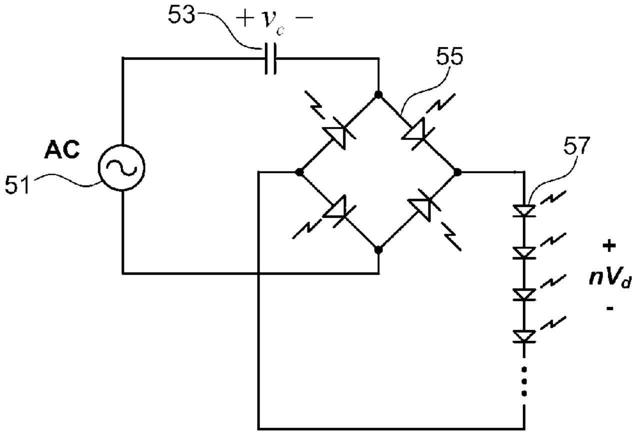
[Fig. 16]



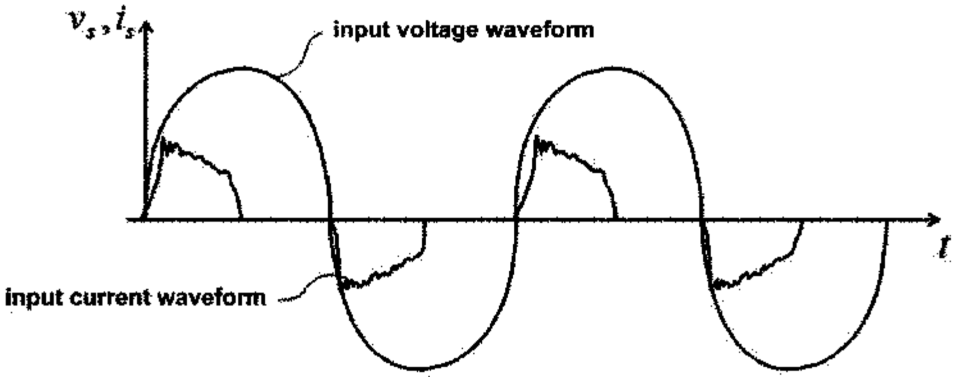
[Fig. 17]



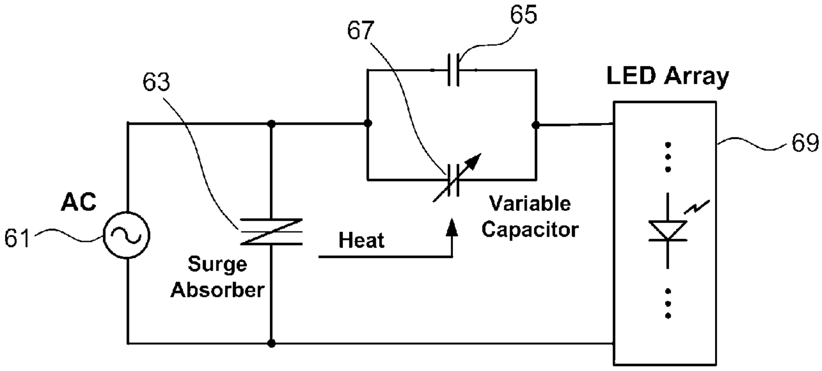
[Fig. 18]



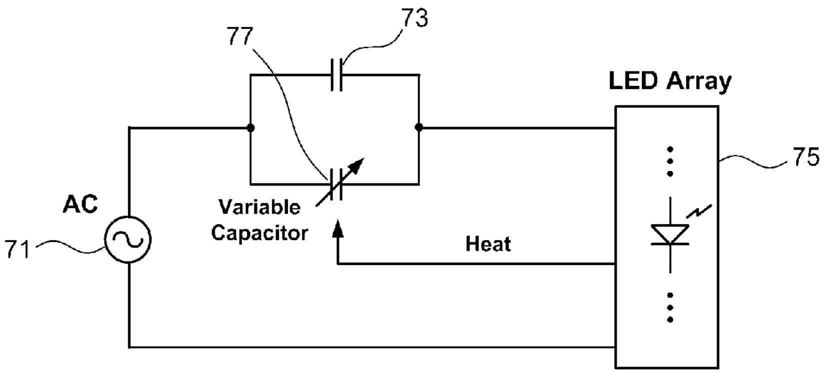
[Fig. 19]



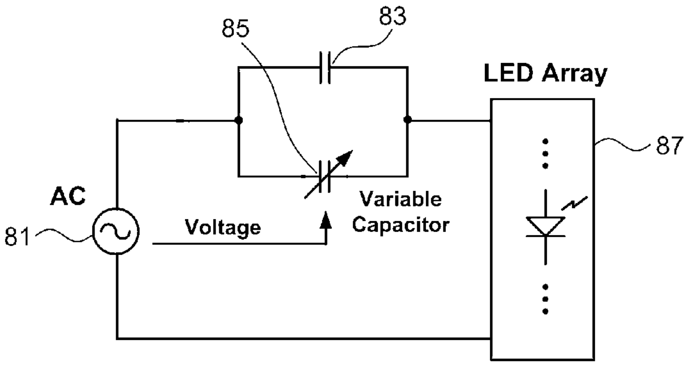
[Fig. 20]



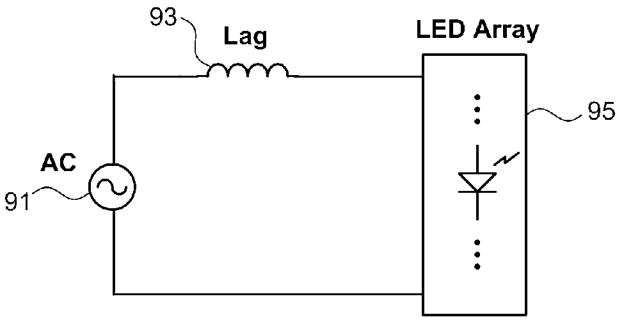
[Fig. 21]



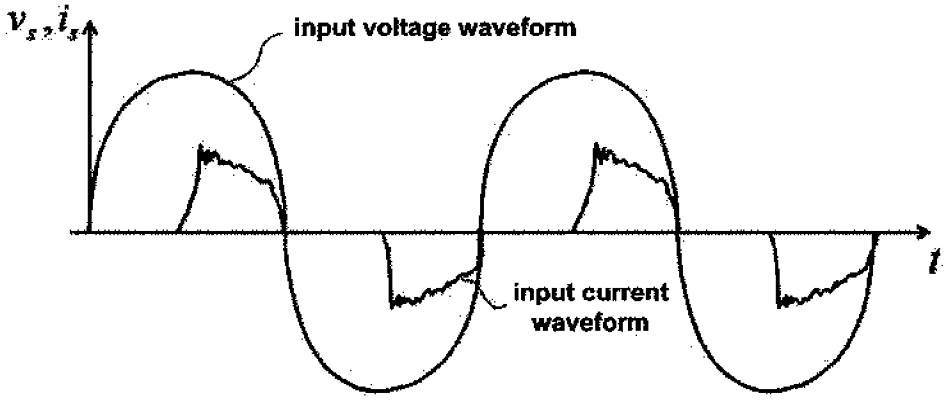
[Fig. 22]



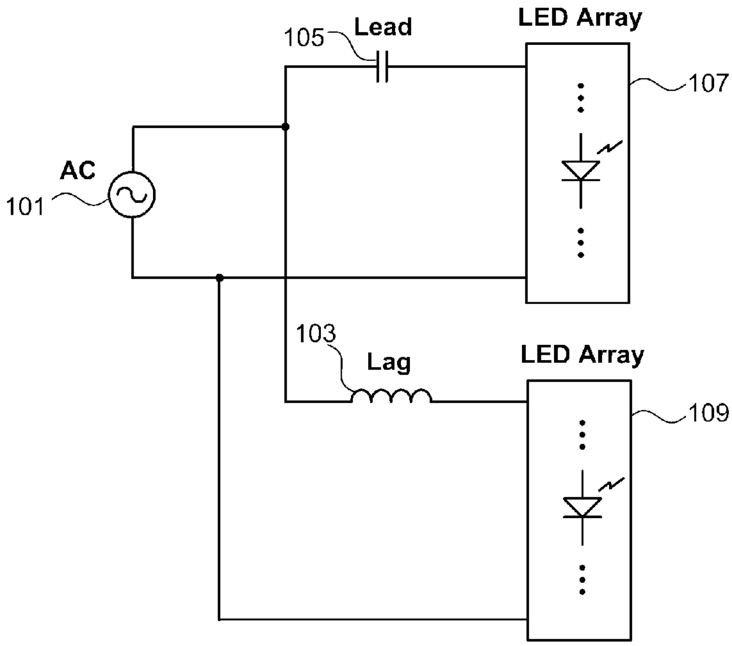
[Fig. 23]



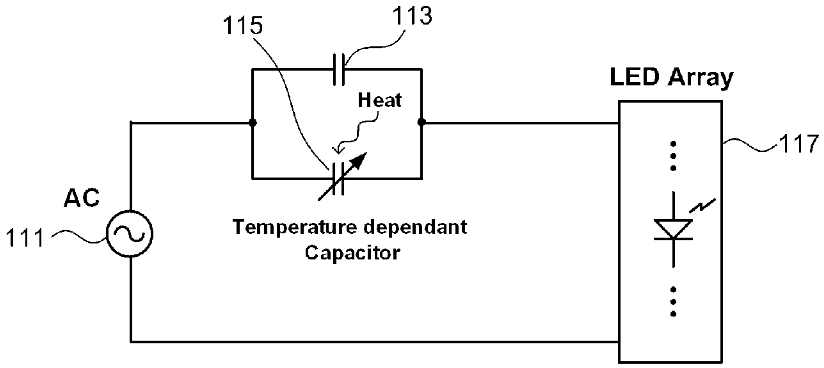
[Fig. 24]



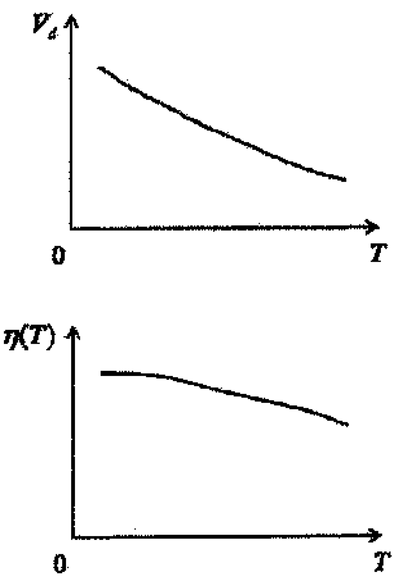
[Fig. 25]



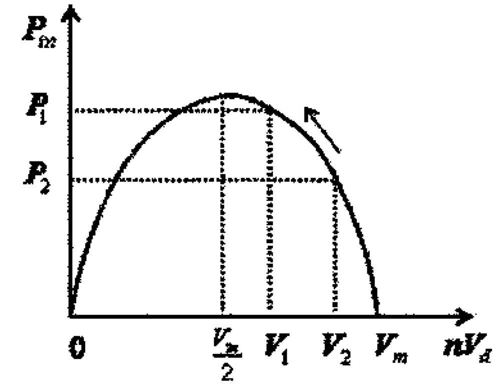
[Fig. 26]



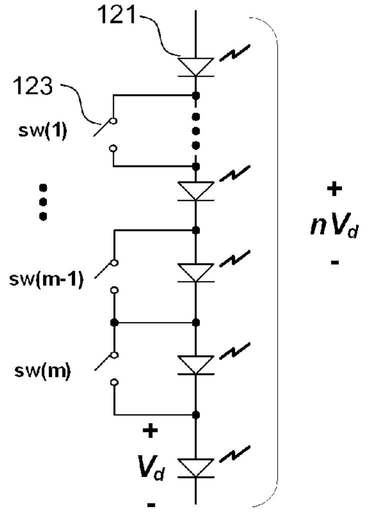
[Fig. 27]



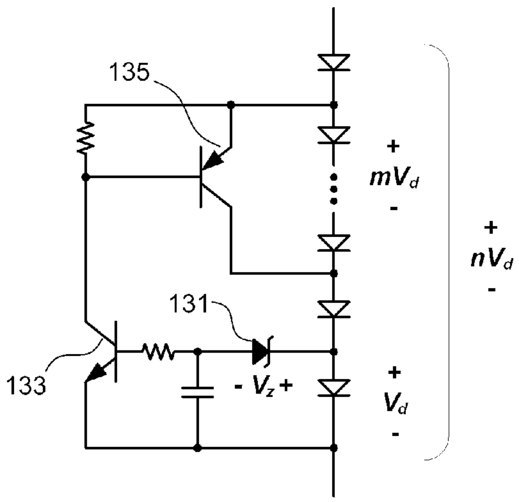
[Fig. 28]



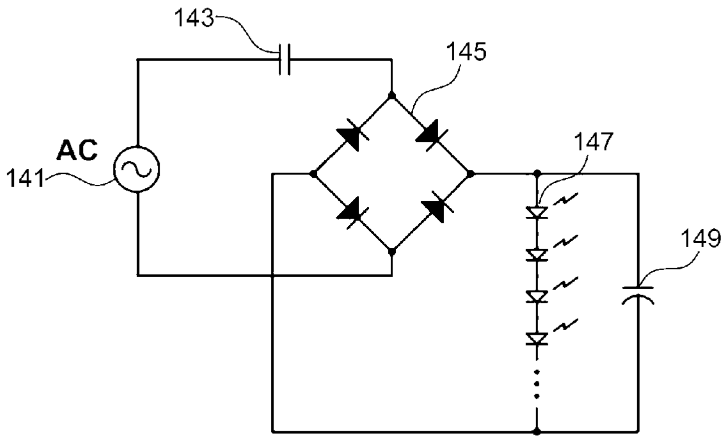
[Fig. 29]



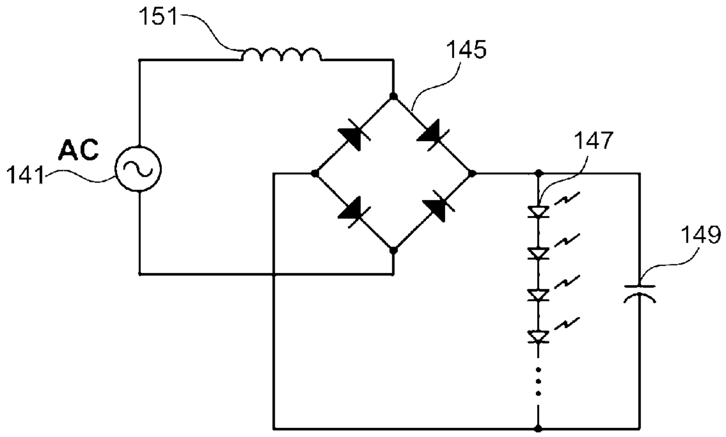
[Fig. 30]



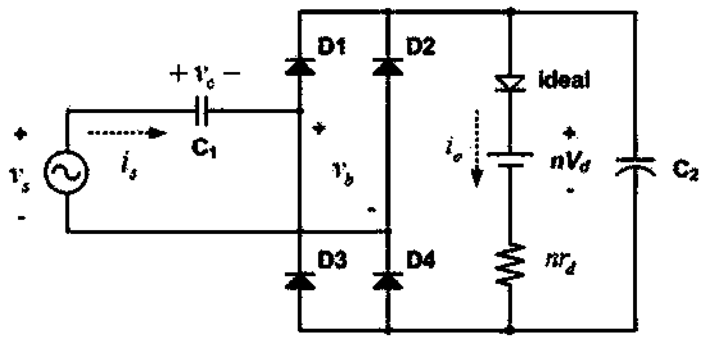
[Fig. 31]



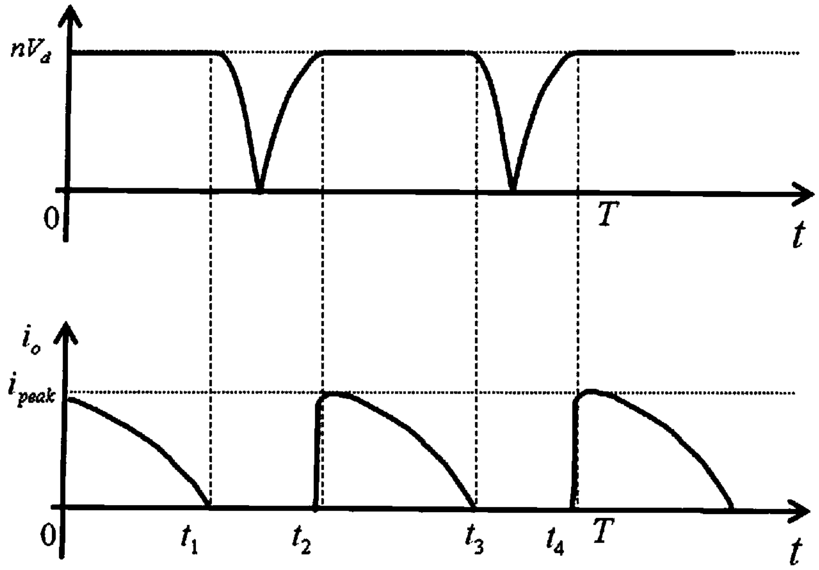
[Fig. 32]



[Fig. 33]

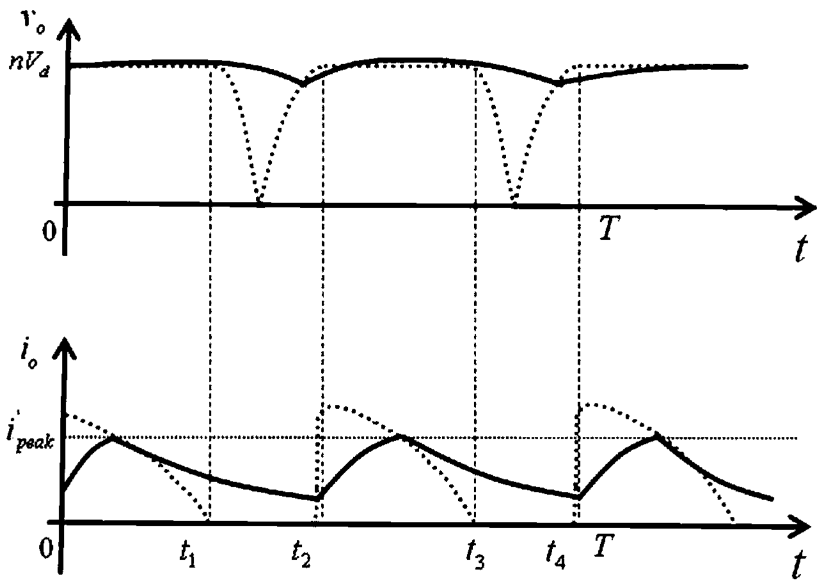


[Fig. 34]



nV_d
0
T
t
i_o
i_{peak}
0
t_1
t_2
t_3
t_4
T
t

[Fig. 35]



v_o
nV_d
0
T
t
i_o
i'_{peak}
0
t_1
t_2
t_3
t_4
T
t