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(54) **Title:** LED DRIVER CIRCUIT WITH INRUSH CURRENT LIMITATION

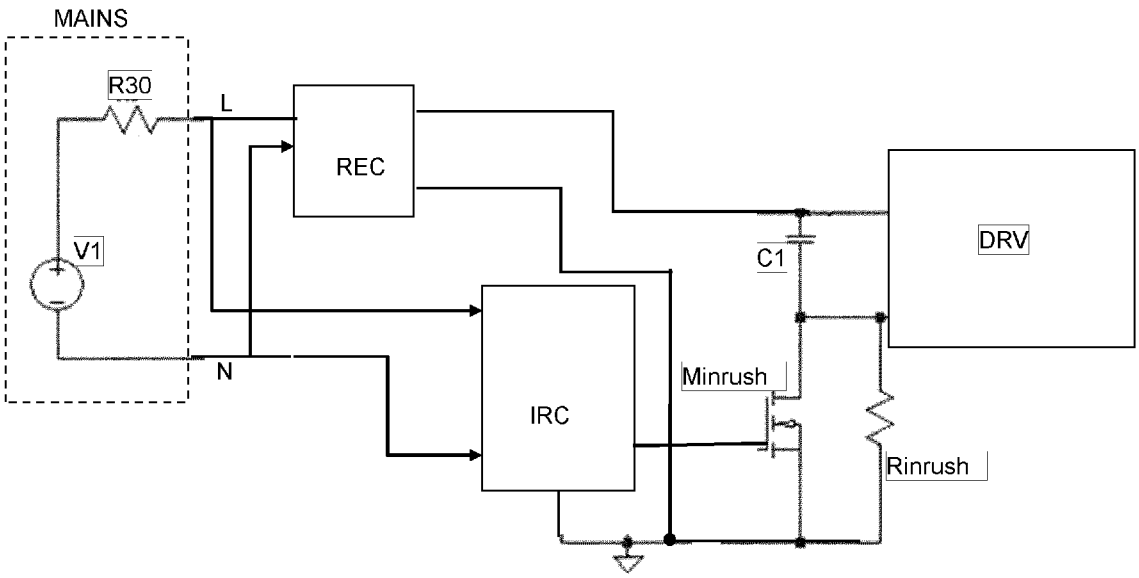

FIG. 3

(57) **Abstract:** A LED driver circuit uses a current limiting resistor in series with the LED driver. A transistor in parallel with the current limiting resistor is used for shorting the current limiting resistor when the transistor is actuated, and is actuated by control circuit when a threshold voltage is reached at an input to the control circuit. The current limiting resistor is not only used at start up, but may also be employed at the start of each AC cycle, in particular if a phase cut diming input signal is received.

[Continued on next page]

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LED driver circuit with inrush current limitation

FIELD OF THE INVENTION

This invention relates to circuits for limiting inrush currents to a load. In particular, the invention is of interest for LED driver circuits which are able to be driven by a phase cut dimmer.

BACKGROUND OF THE INVENTION

High efficiency LED lamps which must work with different dimmers require additional circuitry to enable the lamps to be driven by the signal generated by a dimmer.

A LED lamp driver for example comprises an AC input, a rectifier, and a switch mode converter, such as a boost converter, driven by the rectified voltage.

One approach to enable compatibility with a phase-cut dimmer is to provide a RC latch network at the AC input or at the DC bus (after rectification). The latch circuit enables better compatibility with phase-cut dimmers by drawing sufficient current at the moment of the mains edge (when dimmer goes ON). It also damps oscillations in the mains current which could lead to undesired switching OFF of a dimmer.

It is also important to limit the inrush current to the LED lamp. This is usually achieved with a rather high ohmic resistor in series with the lamp to prevent high inrush currents, especially when the lamp driver comprises a power factor correction (PFC) boost converter. Limiting the inrush current is important in order to limit the switching current of the light switch, so that more lamps can be added.

The series resistor is shorted by a field effect transistor (FET) once the circuit has reached a stable state, so that it provides an increased resistance only during the time when an inrush current is present. For the control of the FET, the rectified mains voltage is for example sensed with a high ohmic voltage divider, and the FET is switched on once there is a sufficient voltage. When the FET is conducting, the input current does not pass through the input resistor and in that way losses are eliminated. In some cases, a limiting Zener diode is added to protect the gate voltage of the FET.

A problem with this circuit is that if the FET is not fully turned off, because the FET gate is not fully discharged, a high inrush current may still flow. This can arise when a phase-cut dimmer input is present.

There is therefore a need for an improved inrush current limiting circuit.

SUMMARY OF THE INVENTION

The invention is defined by the claims.

According to examples in accordance with an aspect of the invention, there is provided a LED driver circuit, comprising:

an input for receiving an AC input signal;

a rectifier for rectifying the AC input signal;

a LED driver supplied by the rectified AC input signal, wherein the output of the LED driver is for driving a load;

a current limiting resistor for connection in series with the LED driver;

a transistor in parallel with the current limiting resistor for shorting the current limiting resistor when the transistor is actuated; and

an inrush current control circuit coupled to the AC input signal, which is configured to control the transistor so that in the AC input signal, the transistor is turned on and off, for the AC input signal comprising a phase-cut AC dimming input signal.

In this way, the current limiting resistor is not only used at start up, but may also be employed at the start of each AC cycle. This will arise in particular if a phase cut diming input signal is received. In particular, the inrush current control circuit is configured to discharge the control voltage applied to the transistor below the threshold voltage for the transistor in the case of dimming, so that the transistor is open circuit when the next rising edge of a rectified phase cut dimming signal is applied to the LED driver circuit. Thus, the current limiting resistor then limits the rising edge of the input voltage for each AC cycle.

Preferably, the inrush current control circuit is coupled to the AC input signal directly. In other words, the inrush current control circuit is coupled to the AC input signal such that it receives the AC input signal and not a rectified version of the AC input signal i.e., the AC input signal before rectification.

Preferably, the LED driver circuit is for receiving the AC input signal, which comprises a phase-cut AC dimming input signal.

The LED driver circuit thereby provides effective limitation of the initial inrush current when the circuit is initially powered on, and also provides effective limitation of a repetitive inrush current when a dimmer is connected.

The inrush current control circuit for example comprises:

a transistor control circuit for actuating the transistor when a threshold voltage is reached at an input to the control circuit; and

a voltage divider across the AC input signal, wherein the output of the voltage divider is provided to the input to the transistor control circuit.

By using a divided voltage from the AC side of the circuit (e.g. a phase cut dimming signal, before rectification) to control use of the current limiting resistor, the current limiting resistor is not only used at start up, but may also be employed at the start of each AC cycle.

The circuit may be used with or without a dimmer circuit. When a dimmer circuit is not connected, the circuit limits the initial start-up inrush current. After start-up, the transistor is then continuously turned ON, so that the current limiting resistor is shorted and does not affect converter efficiency. With a dimmer in the circuit, the LED driver circuit again limits the initial/start-up inrush current but it also limits inrush current every time the dimmer is turned on. This happens in each half-cycle of the mains, because a repetitive inrush current is generated.

This invention thus performs a cycle-by-cycle current inrush current limiting function when a dimmer is added. The inrush current limiting components (of the inrush current control circuit) may also be used to perform the function of an RC latch so avoiding the need for additional components for the RC latch.

The control circuit may comprise an RC filter comprising a capacitor and resistor in parallel with each other, and a Zener diode in parallel with the RC filter, connected between a control terminal of the transistor and a ground terminal.

The RC filter functions as a latch.

A capacitor is for example provided at the input to the LED driver. This functions as an EMI filter.

The voltage divider for example comprises a first resistor between a first terminal of the input and the input to the control circuit and a second resistor between a second terminal of the input and the input to the control circuit. The first and second resistors for example have equal value.

The voltage divider for example comprises a first unidirectional device between a first terminal of the input and the input to the transistor control circuit and a second unidirectional device between a second terminal of the input and the input to the transistor control circuit.

The LED driver typically comprises a boost converter.

The invention also provides a lighting circuit comprising:

the LED driver circuit as defined above; and

an LED arrangement driven by the LED driver circuit.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, in which:

Fig. 1 shows a known LED driver circuit with an inrush current limiter to provide higher efficiency;

Fig. 2 shows waveforms which arise during the operation of the circuit of Fig. 1;

Fig. 3 shows a first example of a LED driver circuit in accordance with the invention;

Fig. 4 shows a second example of a LED driver circuit in accordance with the invention;

Fig. 5 shows first waveforms which arise during the operation of the circuit of Fig. 4 with a non-dimming input;

Fig. 6 shows second waveforms which arise during the operation of the circuit of Fig. 4 with a phase-cut dimming input; and

Fig. 7 shows a third example of a LED driver circuit in accordance with the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The invention will be described with reference to the Figures.

It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are

intended for purposes of illustration only and are not intended to limit the scope of the invention. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

The invention provides a LED driver circuit which uses a current limiting resistor in series with the LED driver. A transistor in parallel with the current limiting resistor is used for shorting the current limiting resistor when the transistor is actuated, and is actuated by control circuit when a threshold voltage is reached at an input to the control circuit. The current limiting resistor is not only used at start up, but may also be employed at the start of each AC cycle, in particular if a phase cut diming input signal is received.

Figure 1 shows a known LED driver circuit.

The AC input is represented by voltage source V1. This may be a mains signal, or it may be a mains signal that has been cut by a phase-cut dimmer.

The AC signal is rectified by rectifier REC. The rectified voltage is provided as input to a LED driver DRV, which for example comprises a switch mode power converter. A capacitor C1 at the input to the LED driver provides an EMI filter function. The LED driver DRV is for example a boost converter, such as a power factor correction boost converter.

The output of the LED driver DRV is connected to the load, which is a LED arrangement, shown schematically as a single LED, LED1.

The LED driver is in series with a current limiting resistor Rinrush. Since the LED arrangement is connected across the output of the LED driver, it may also be considered to be in series with the current limiting resistor. Thus, the LED drive current generated by the LED driver flows from the positive rectified input voltage terminal, through the LED arrangement, through the current limiting resistor, and to ground.

The current limiting resistor can be shorted by transistor Minrush so that the series current instead flows through the transistor. This will give rise to lower losses but will not provide a current limiting function. When the current limiting resistor is not shorted, it provides the current limiting function, in particular to limit inrush currents which arise at the start up of the circuit. This function consumes power, so it is disabled after start-up, by actuating the transistor Minrush to provide a parallel short.

The transistor is controlled by a transistor control circuit comprising a parallel RC filter formed of a parallel capacitor C10 and resistor R11, both in parallel with a Zener diode D10. The output of the transistor control circuit connects to the gate of the transistor. The transistor control circuit is supplied with the rectified input voltage to the LED driver through resistor R10.

The resistor R10 has high ohmic resistance (e.g. 6 MΩ) so it forms a high-ohmic voltage divider with the Zener diode D10. The Zener diode D10 protects the gate voltage of the FET. There may instead be a simple resistive divider.

Figure 2 shows waveforms which arise during the operation of the circuit of Figure 1.

The top pane shows a sinusoidal AC mains input signal 10 as well as a phase-cut dimming signal 12.

The second pane shows the gate voltage applied to the transistor. Plot 20 is for the full AC mains signal and plot 22 is for the phase-cut mains signal.

The third pane shows the current flowing 30 through the transistor. The tall spikes are for the case of a phase-cut dimming input. They correspond in timing with the steep edges of the phase-cut dimming signal.

The bottom pane shows the current flowing 40 through the current limiting resistor. In both cases (dimming and non-dimming), the transistor remains turned on after the initial start up phase.

When the phase-cut dimming signal is received, the LED driver stops operating at a certain input voltage, but a voltage remains on the capacitor C10 of the transistor control circuit so that the transistor Minrush remains turned on. A current thus continues to flow through the FET and not through the inrush resistor. As result, the input current is much higher as shown by the large current spikes.

The invention provides a modification to the circuit such that during each cycle, in the case of a phase-cut dimming signal, the gate of the transistor is discharged below its threshold. In this way, the transistor is open when the edge of the phase-cut dimming signal arrives, and the current limiting resistor performs a current limiting function each time there is a rising edge of the input voltage.

Figure 3 shows a first example of a LED driver circuit in accordance with the invention with the load, preferably an LED arrangement, omitted for clarity.

The same components are given the same references as in Figure 1 and perform the same functions.

Thus, the circuit again comprises an AC input source V1 (a mains impedance is also shown as R30) which is rectified by rectifier REC which supplies a LED driver DRV. The same current limiting resistor Rinrush and transistor Minrush are shown. The transistor is controlled by an inrush current control circuit IRC.

The inrush current control circuit IRC generates the input signal to the transistor control circuit for controlling the transistor Minrush in a different manner to the circuit of Figure 1. In particular, the inrush current control circuit is connected to the AC input signal (L,N), and it controls Minrush so that in each cycle the transistor is turned on and off when a dimmer is connected. If no dimmer is connected, the transistor Minrush is always on.

Figure 4 shows an example of an implementation of the LED driver circuit of Figure 3 (again with the LED arrangement omitted for clarity).

The same components are given the same references as in Figure 3 and perform the same functions.

Thus, the circuit again comprises the AC input source V1 rectified by rectifier REC which supplies the LED driver DRV. The inrush current control circuit includes the transistor control circuit as shown in Figure 1, comprising capacitor C10. Resistor R11, and Zener diode D10.

The modification compared to Figure 1 is that AC resistors R20 and R21 are used to from the input signal to the transistor control circuit. These resistors form a voltage divider (R20, R21) across the AC input signal (i.e., at the input side of the rectifier), and output of the voltage divider (R20, R21) is provided to the input to the control circuit.

The effect of this change is that the gate voltage to the transistor remains high when a non-dimming input signal is received, but when a phase-cut dimming input is received, the gate voltage drops below the threshold voltage of the transistor in each half cycle of the mains input.

Figure 5 shows the circuit waveforms for a non-dimming input 10. The gate voltage applied to the transistor is again shown as plot 20, the current flowing through the transistor is shown as plot 30 and the current flowing through the current limiting resistor is shown as plot 40.

As can be seen, the current limiting resistor is only used at start up, after which the transistor remains turned on.

Figure 6 shows the circuit waveforms for a phase-cut dimming input 12. The gate voltage applied to the transistor is again shown as plot 22, the current flowing through

the transistor is shown as plot 30 and the current flowing through the current limiting resistor is shown as plot 40.

The gate voltage now drops periodically below the gate threshold so that the transistor turns off. Thus, there are repeated periods of no current through the transistor. Similarly, there are current spikes of current flowing through the current limiting resistor, timed with the steep edges of the phase-cut dimming signal. In this way, current flows first through the current limiting resistor then through the transistor, for each half cycle of the phase-cut dimming input.

Figure 4 shows an additional RC network Rdamp1, Cdamp1. This is a known latch circuit added to the bus voltage to damp the network to prevent false.

This latch circuit will give extra losses. However, in the circuit of Figure 4 (without the latch circuit), each time the transistor Minrush1 is open, a network of C1 and Rinrush is present, and this can perform same role for damping the dimming. Thus, a latch circuit Rdamp1 and Cdamp1 is not needed because C1 and Rinrush perform the desired function.

The circuit of Figure 4 uses a resistive voltage divider R20, R21 from the mains input side to the inrush current control circuit.

Figure 7 shows an alternative circuit design using a diode voltage divider circuit D21, D21 which connects to the inrush current control circuit through an input resistor R30. Preferably, the inrush current control circuit comprises a transistor control circuit for actuating the transistor when a threshold voltage is reached at an input to the transistor control circuit. A first unidirectional device D20 between a first terminal of the input and the input to the transistor control circuit and a second unidirectional device D21 between a second terminal of the input and the input to the transistor control circuit. Preferably, the unidirectional devices are diodes. The cathodes of the diodes may be coupled to the transistor control circuit.

Thus, in summary, the inrush current limiting circuit described above enables a high-efficiency design of phase-cut dimmable driver with effective limitation of the initial inrush current, after power ON as well as effective limitation of repetitive inrush currents when a dimmer is connected. A typical RC latch circuit is not needed so that the overall circuit size is reduced.

Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the

disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A LED driver circuit, comprising:

an input for receiving an AC input signal (V1);

a rectifier (REC) for rectifying the AC input signal;

a LED driver (DRV) supplied by the rectified AC input signal, wherein the output of the LED driver is for driving a load;

a current limiting resistor (Rinrush) for connection in series with the LED driver (DRV);

a transistor (Minrush) in parallel with the current limiting resistor for shorting the current limiting resistor when the transistor is actuated; and

an inrush current control circuit coupled to the AC input signal, which is configured to control the transistor (Minrush) so that the transistor (Minrush) is turned on and off by the AC input signal.

2. The LED driver circuit of claim 1, wherein the inrush current control circuit comprises:

a transistor control circuit for actuating the transistor when a threshold voltage is reached at an input to the transistor control circuit; and

a voltage divider (R20, R21) across the AC input signal, wherein the output of the voltage divider (R20, R21) is provided to the input to the transistor control circuit.

3. The LED driver circuit of claim 2, wherein the transistor control circuit comprises an RC filter comprising a capacitor (C10) and resistor (R11) in parallel with each other, and a Zener diode (D10) in parallel with the RC filter, connected between a control terminal of the transistor and a ground terminal.

4. The LED driver circuit of any one of claims 2 to 3, wherein the voltage divider comprises a first resistor (R20) between a first terminal of the input and the input to the transistor control circuit and a second resistor (R21) between a second terminal of the input and the input to the transistor control circuit.

5. The LED driver circuit of claim 4, wherein the first and second resistors (R20, R21) have equal value.

6. The LED driver circuit of any one of claims 1 to 5, comprising a capacitor (C1) at the input to the LED driver.

7. The LED driver circuit of any one of claims 1 to 6, wherein the LED driver comprises a boost converter.

8. The LED driver circuit of claim 1, wherein the inrush current control circuit comprises:

a transistor control circuit for actuating the transistor when a threshold voltage is reached at an input to the transistor control circuit; and

a first unidirectional device (D20) between a first terminal of the input and the input to the transistor control circuit and a second unidirectional device (D21) between a second terminal of the input and the input to the transistor control circuit.

9. A lighting circuit comprising:

the LED driver circuit of any one of claims 1 to 8; and

an LED arrangement driven by the LED driver circuit.

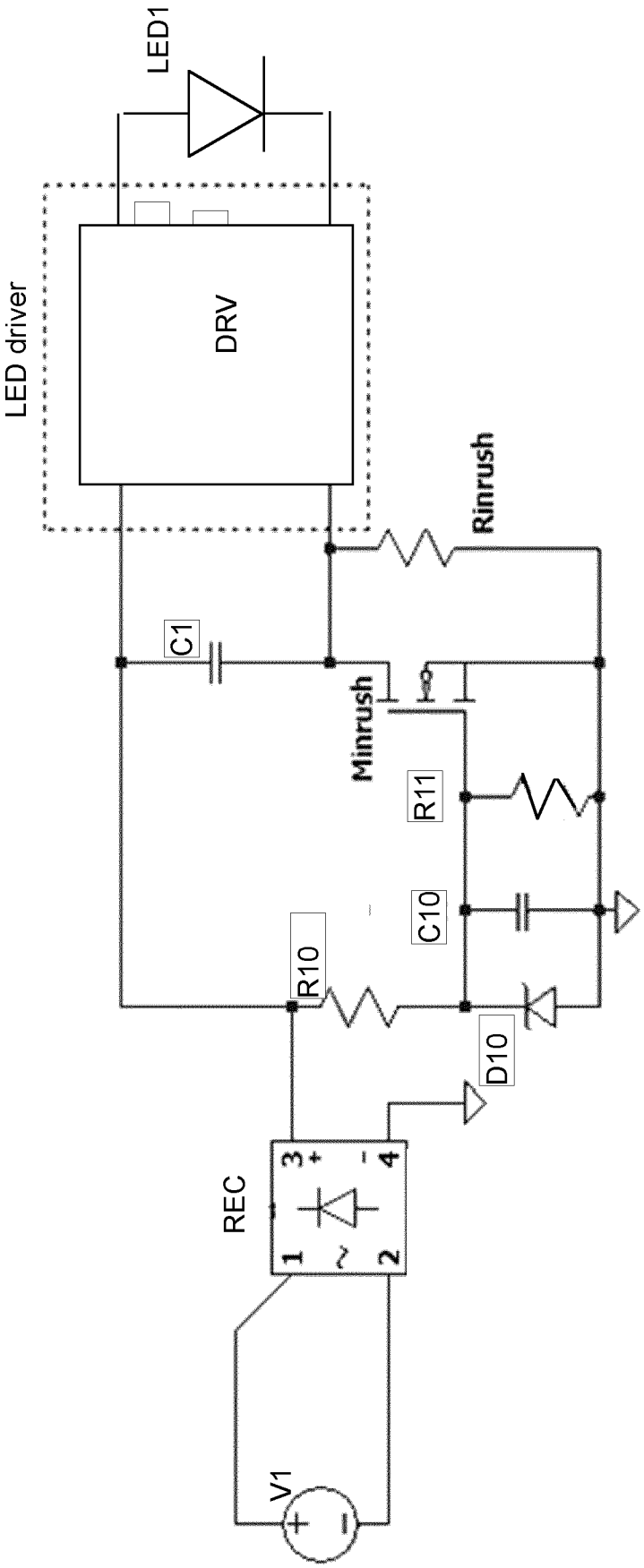
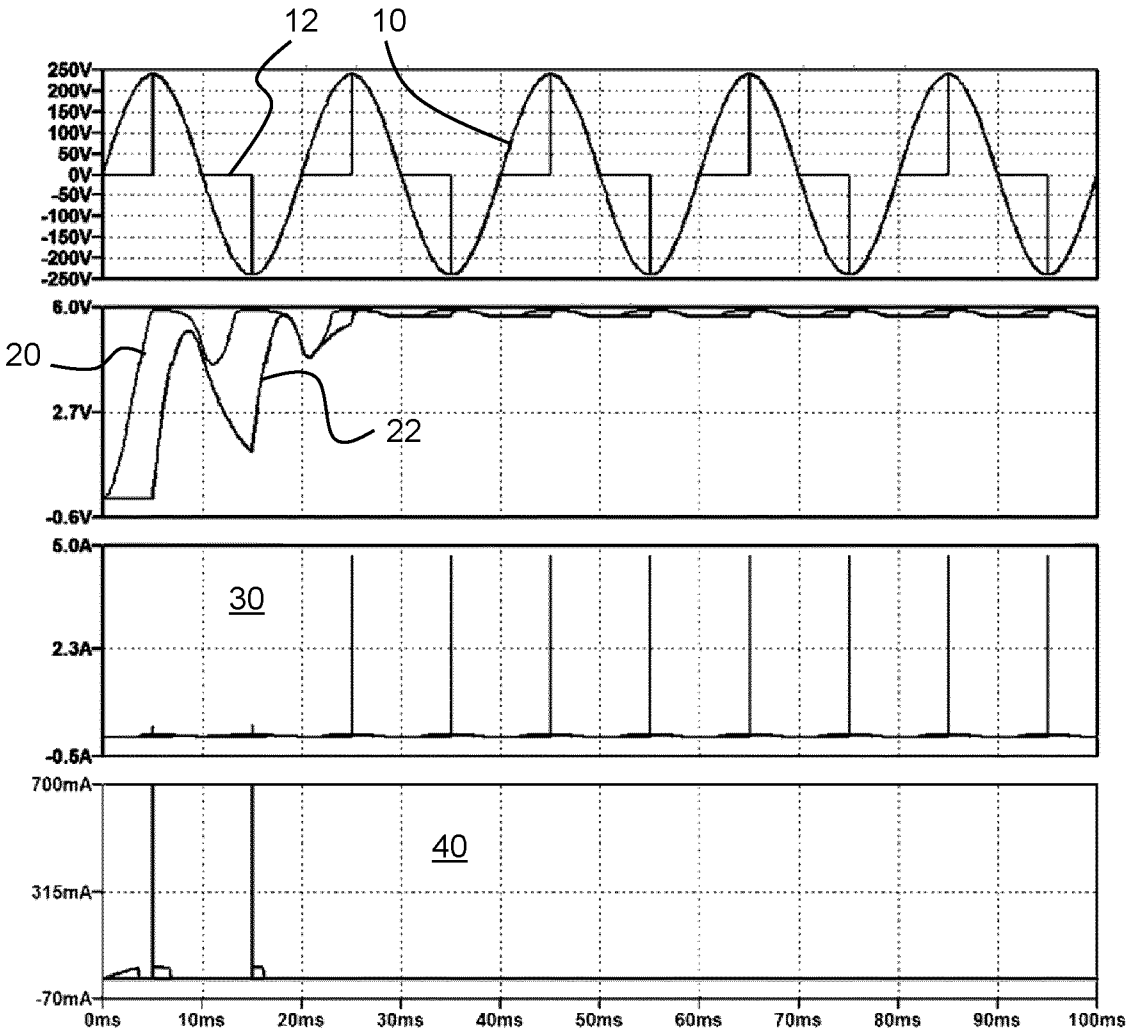

LED1
LED driver
DRV
Rinrush
C1
Minrush
R11
C10
R10
D10
REC
3
4
1
2
V1

FIG. 1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150V
100V
50V
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-50V
-100V
-150V
-200V
-250V
6.0V
20
2.7V
22
-0.6V
5.0A
30
2.3A
-0.5A
700mA
40
315mA
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100ms

FIG. 2

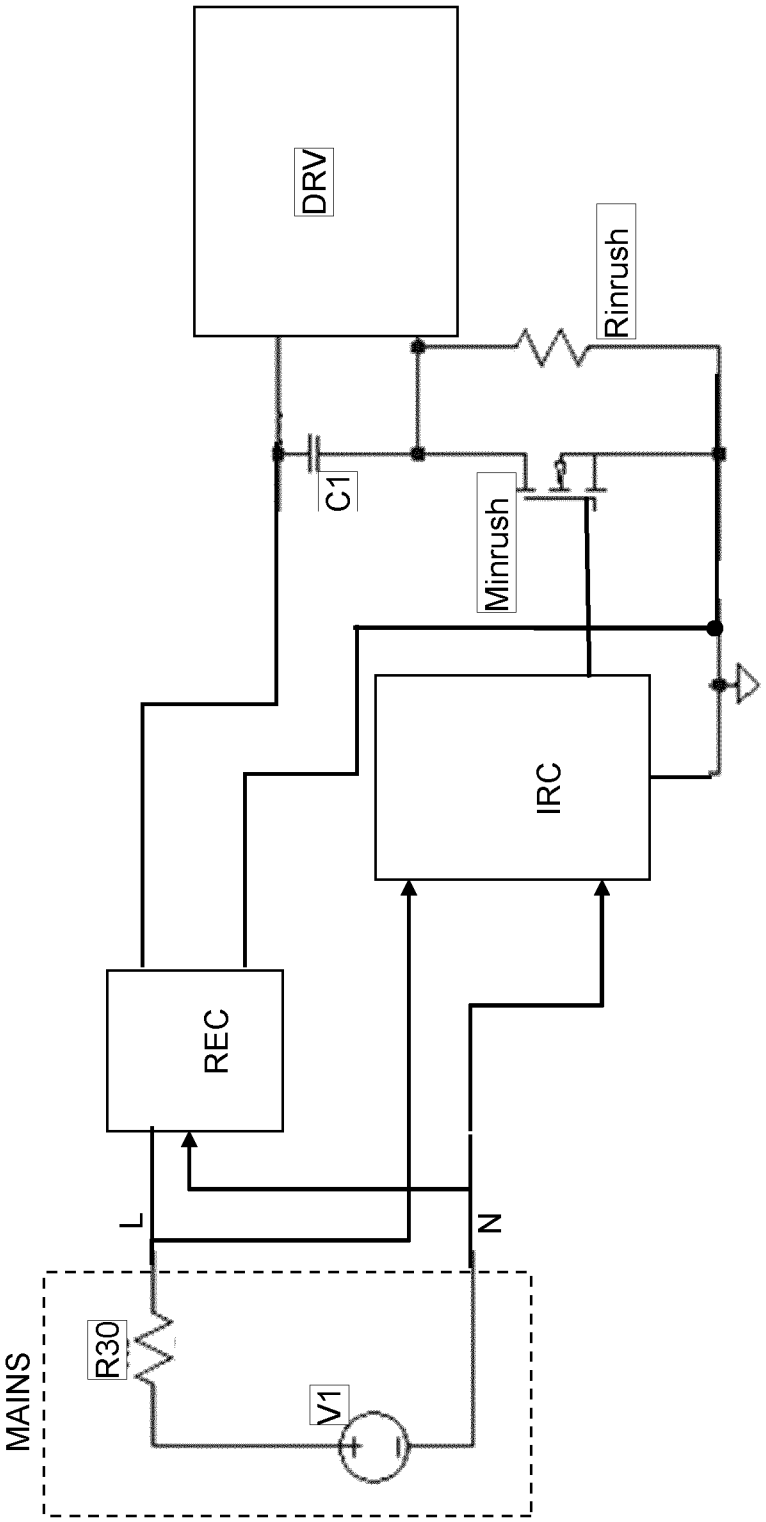

FIG. 3

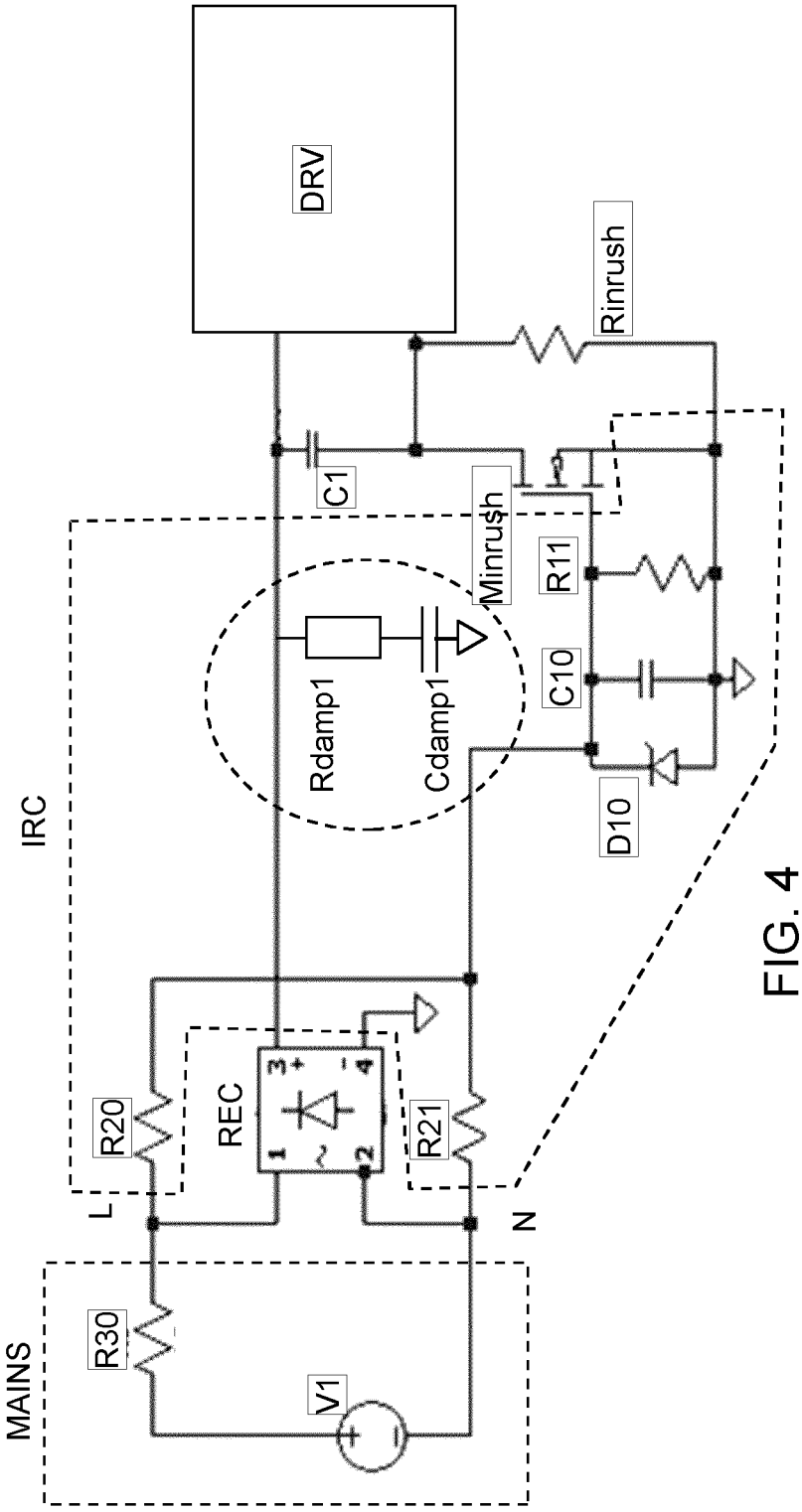
DRV
Rinrush
C1
Minrush
R11
C10
D10
Rdamp1
Cdamp1
IRC
REC
R20
R21
L
N
R30
V1
MAINS

FIG. 4

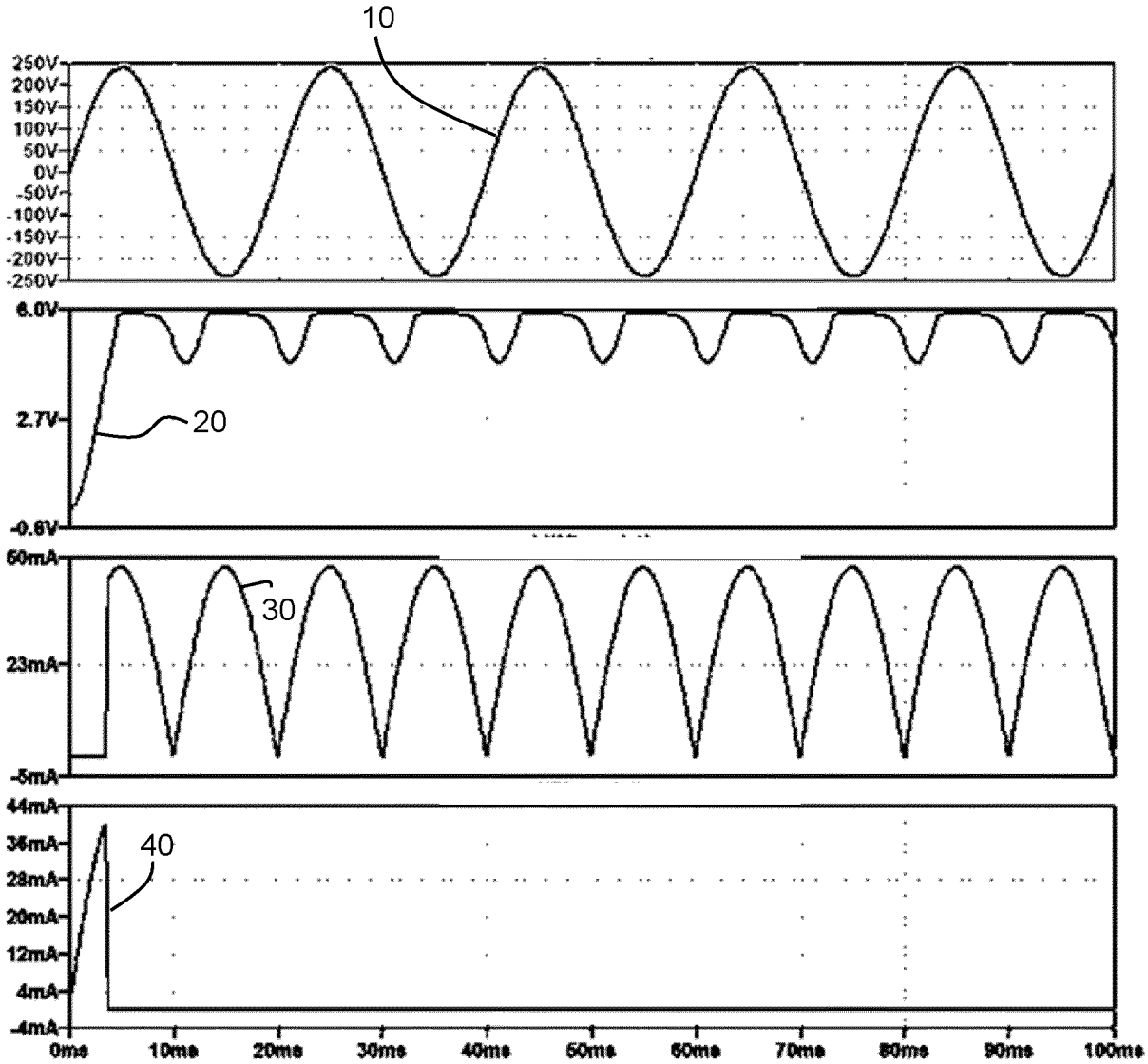
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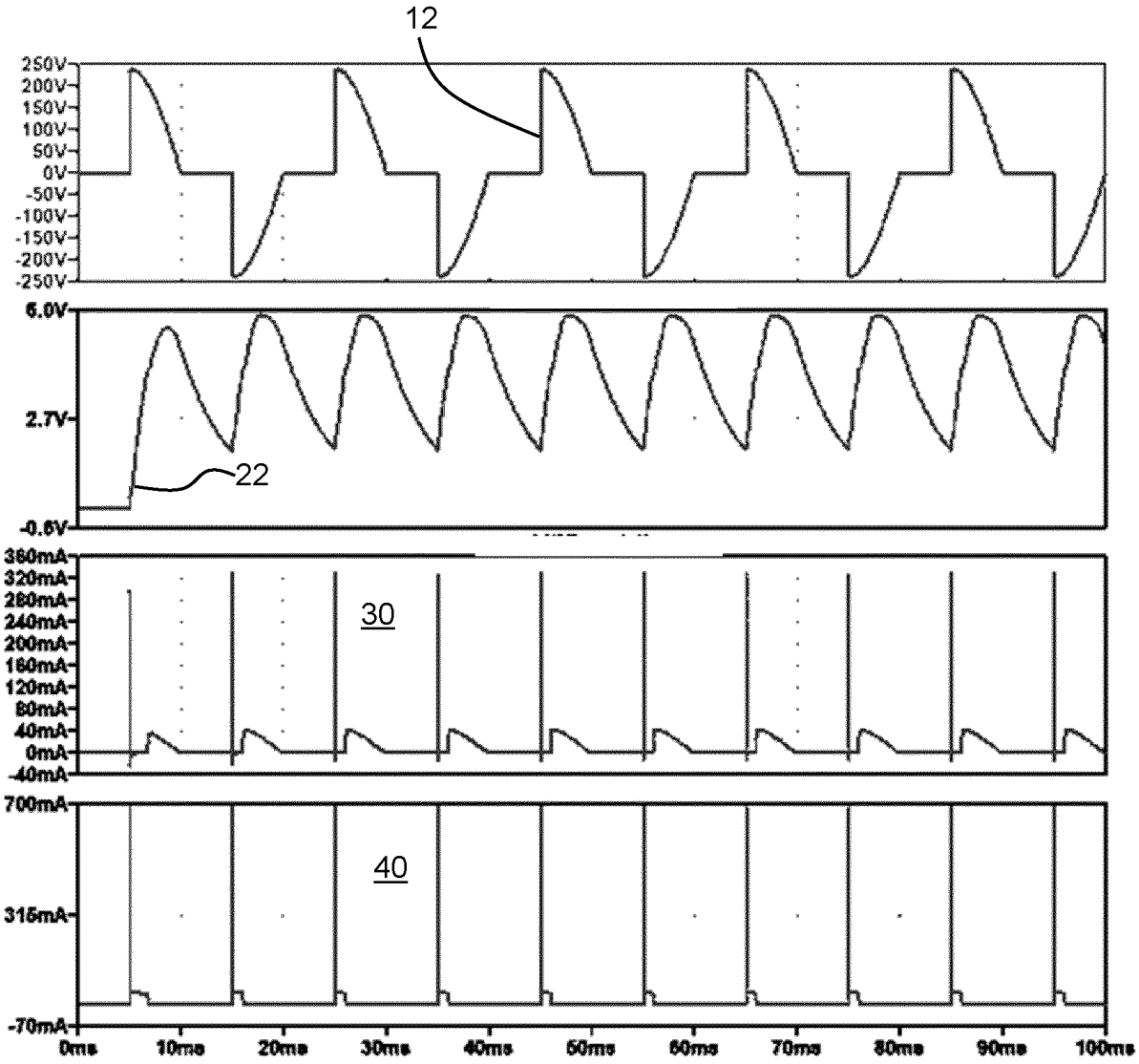
FIG. 5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22
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160mA
120mA
80mA
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0mA
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FIG. 6

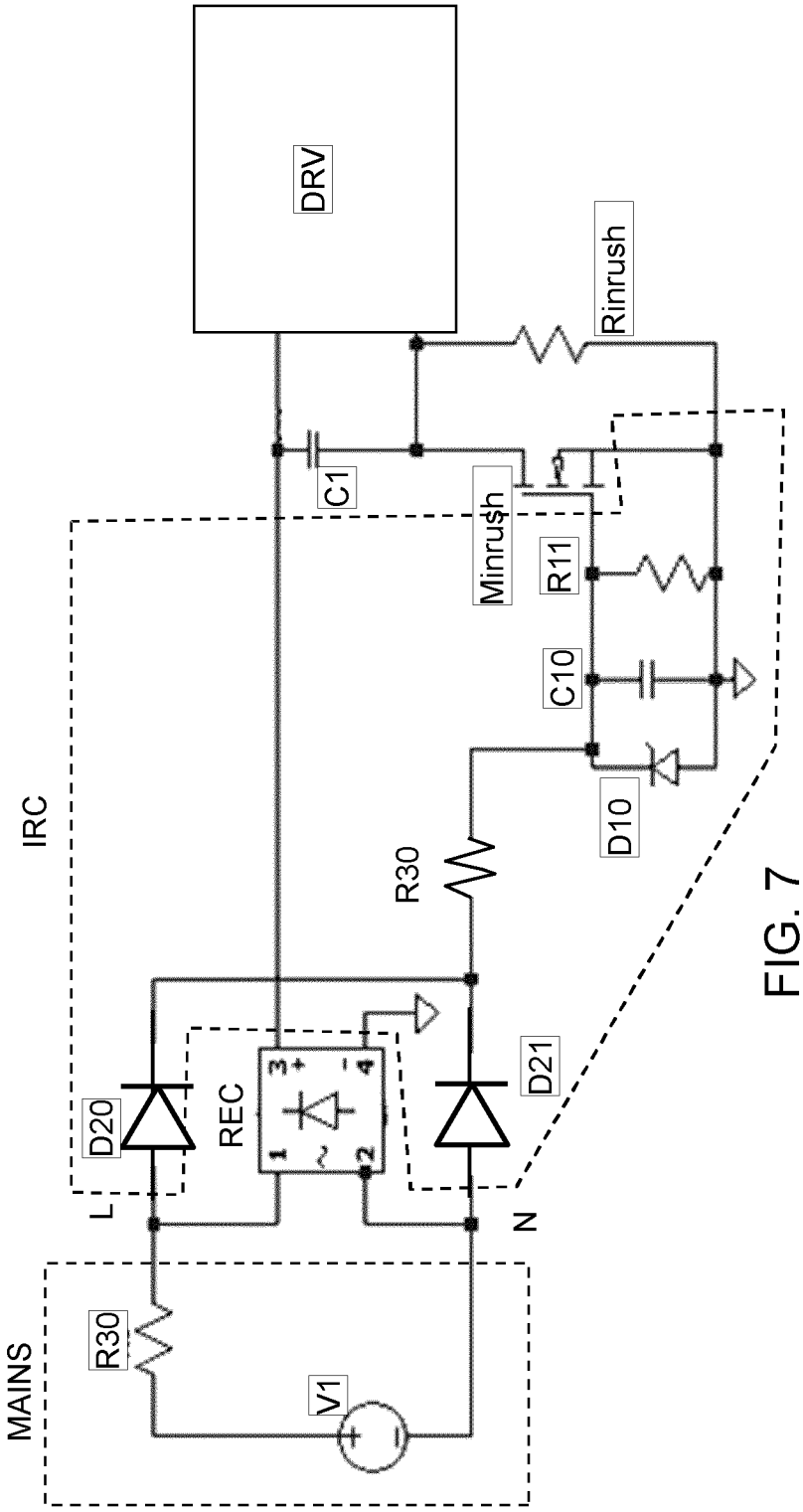
DRV
Rinrush
C1
Minrush
R11
C10
D10
IRC
R30
D21
D20
REC
3+
4-
1
2
L
N
MAINS
R30
V1

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/065905

A. CLASSIFICATION OF SUBJECT MATTER

INV. H05B45/31 H05B45/315 H05B45/50
ADD. H05B45/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/187543 A1 (CHANG LON-KOU [TW] ET AL) 25 July 2013 (2013-07-25)	1,6,7,9
A	paragraphs [0005], [0020] - [0040]; figures 2-4	2-5,8
X	US 2009/195168 A1 (GREENFELD FRED [US]) 6 August 2009 (2009-08-06)	1,2,4-7, 9
A	paragraphs [0009] - [0037]; figure 1	3,8

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
26 July 2024	25/09/2024

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/065905

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