Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2806407 C 2016/03/15

(11)(21) **2 806 407**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) Date de dépôt PCT/PCT Filing Date: 2011/05/20
(87) Date publication PCT/PCT Publication Date: 2012/02/02
(45) Date de délivrance/Issue Date: 2016/03/15
(85) Entrée phase nationale/National Entry: 2013/01/23
(86) N° demande PCT/PCT Application No.: CN 2011/074453
(87) N° publication PCT/PCT Publication No.: 2012/013070
(30) Priorités/Priorities: 2010/07/30 (CN201010245288.0); 2010/08/30 (CN201010274785.3); 2010/12/23 (CN201010603717.7)

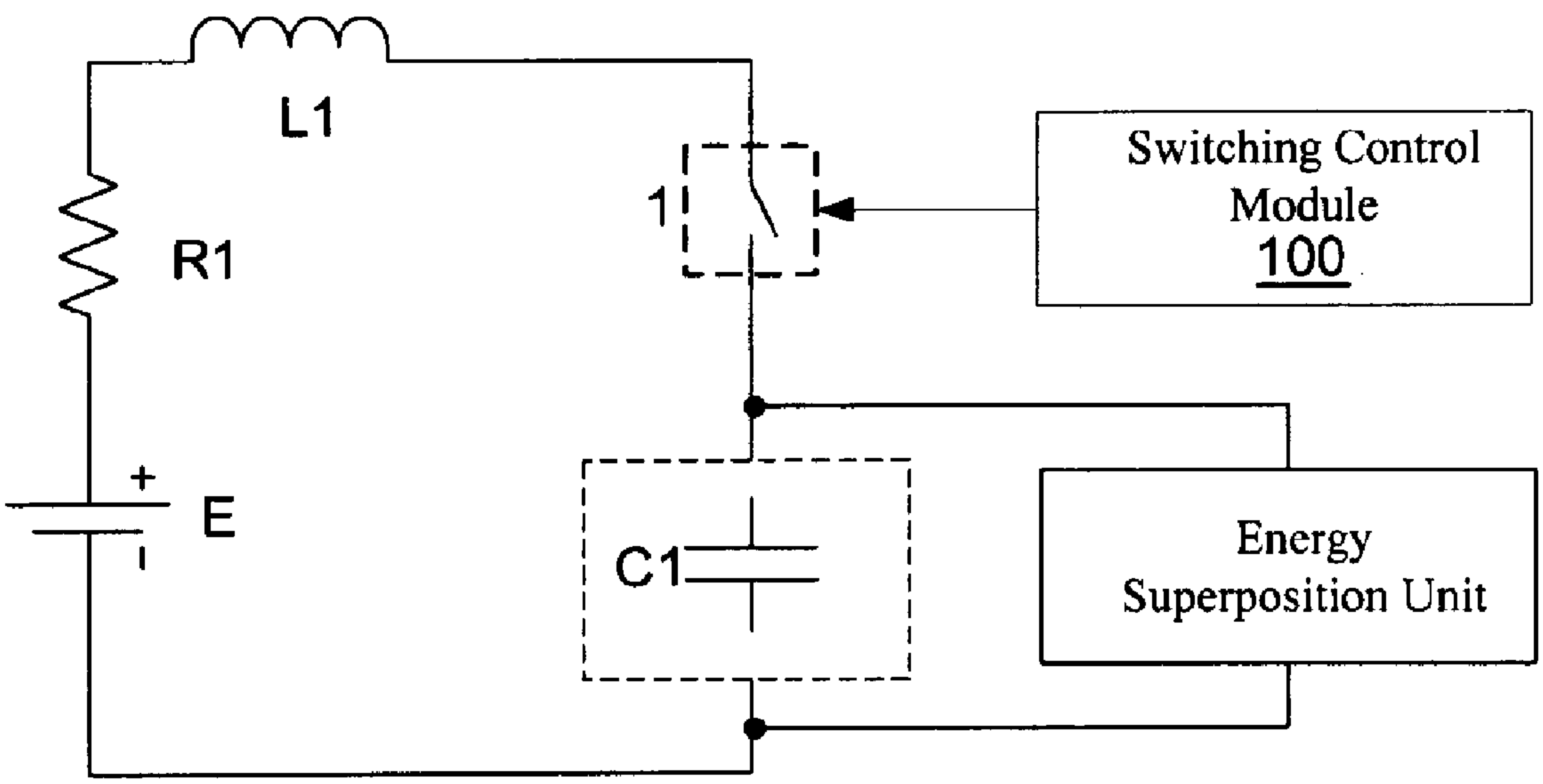
(51) Cl.Int./Int.Cl. *H01M 10/657* (2014.01), *H01M 10/615* (2014.01), *H01M 6/50* (2006.01)

(72) Inventeurs/Inventors:
XU, WENHUI, CN;
HAN, YAOCHUAN, CN;
FENG, WEI, CN;
YANG, QINYAO, CN;
XIA, WENJIN, CN;
MA, SHIBIN, CN

(73) Propriétaires/Owners:
SHENZHEN BYD AUTO R&D COMPANY LIMITED, CN;
BYD COMPANY LIMITED, CN

(74) Agent: SMART & BIGGAR

(54) Titre : CIRCUIT DE CHAUFFAGE DE BATTERIE
(54) Title: BATTERY HEATING CIRCUIT



(57) Abrégé/Abstract:
A battery heating circuit, comprising a switch unit (1), a switching control module (100), a damping element R1, an energy storage circuit, and an energy superposition unit, wherein, the energy storage circuit is connected with the battery, and comprises a current storage element L1 and a charge storage element C1; the damping element R1, switch unit (1), current storage element L1, and charge storage element C1 are connected in series; the switching control module (100) is connected with the switch unit (1), and designed to control ON/OFF of the switch unit (1), so as to control the energy flowing between the battery and the energy storage circuit; the energy superposition unit is connected with the energy storage circuit, and is designed to superpose the energy in the energy storage circuit with the energy in the battery after the switch unit (1) switches on and then switches off. The heating circuit provided in the present invention can improve the charge/discharge performance of a battery, enhance the safety of battery heating, and improve the working efficiency of the heating circuit.

Abstract

A battery heating circuit, comprising a switch unit, a switching control module, a damping element R1, an energy storage circuit, and an energy superposition unit, wherein, the energy storage circuit is connected with the battery, and comprises a current storage element L1 and a charge storage element C1; the damping element R1, switch unit, current storage element L1, and charge storage element C1 are connected in series; the switching control module is connected with the switch unit, and configured to control ON/OFF of the switch unit, so as to control the energy flowing between the battery and the energy storage circuit; the energy superposition unit is connected with the energy storage circuit, and is configured to superpose the energy in the energy storage circuit with the energy in the battery after the switch unit switches on and then switches off. The heating circuit provided in the present invention can improve the charge/discharge performance of a battery, enhance the safety of battery heating, and improve the working efficiency of the heating circuit.

BATTERY HEATING CIRCUIT

Field of the Disclosure

The present invention pertains to electric and electronic field, in particular to a battery heating circuit.

Background of the Disclosure

In view cars have to run under complex road conditions and environmental conditions or some electronic devices are used under harsh environmental conditions, the battery, which serves as the power supply unit for electric motor cars or electronic devices, must be adaptive to these complex conditions. In addition, besides these conditions, the service life and charge/discharge cycle performance of the battery must be taken into consideration; especially, when electric motor cars or electronic devices are used in low temperature environments, the battery is required to have outstanding low temperature charge/discharge performance and higher input/output power performance.

Generally speaking, under low temperature conditions, the resistance of the battery will increase, and so will the polarization; therefore, the capacity of the battery will be reduced.

To keep the capacity of the battery and improve the charge/discharge performance of the battery under low temperature conditions, the present disclosure provides a battery heating circuit.

Summary of the Disclosure

In some cases, it may be desirable to provide a battery heating circuit which may solve the problem of decreased capacity of the battery caused by increased resistance and polarization of the battery under low temperature conditions.

An embodiment of the present disclosure provides a battery heating circuit, comprising a switch unit, a switching control module, a damping element, an energy storage circuit, and an energy superposition unit, wherein, the energy storage circuit is connected with the battery, and comprises a first current storage element and a first charge storage element; the damping element, switch unit, first current storage element, and first charge storage element are connected in series; the switching control module is connected with the switch unit, and configured to control ON/OFF of the switch unit, so as to control the energy flowing between the battery and the energy storage circuit; and the energy superposition unit is connected with the energy storage circuit, and is configured to superpose the energy in the energy storage circuit with the energy in the battery after the switch unit switches on and then switches off.

A heating circuit disclosed herein may improve the charge/discharge performance of a battery. In addition, since an energy storage circuit is connected with the battery in series in the heating circuit, the safety problem related with short circuit caused by failures of the switch unit can be avoided when the battery is heated due to the existence of the charge storage element connected in series, and therefore the battery can be protected effectively. In addition, an energy superposition unit is provided in the heating circuit in an embodiment of the present disclosure, and the energy superposition unit can superpose the energy in the energy storage circuit with the energy in the battery after the switch unit switches on and then switches off, thus, the discharging current in the heating loop will be increased when the switch unit is controlled to switch on at the next time, and therefore the working efficiency of the heating circuit is improved.

Other characteristics and advantages of exemplary embodiments of the present invention will be further elaborated in detail in the embodiments hereafter.

Brief Description of the Drawings

The accompanying drawings, as a part of this description, are provided here to facilitate further understanding on the present invention, and are used in conjunction with the following embodiments to explain the present invention, but shall not be comprehended as constituting any limitation to the present invention. In the figures:

Figure 1 is a schematic diagram of the battery heating circuit provided in the present invention;

Figure 2 is a schematic diagram of an embodiment of the energy superposition unit shown in Figure 1;

Figure 3 is a schematic diagram of an embodiment of the polarity inversion unit shown in

Figure 2;

Figure 4 is a schematic diagram of an embodiment of the polarity inversion unit shown in Figure 2;

Figure 5 is a schematic diagram of an embodiment of the polarity inversion unit shown in Figure 2;

Figure 6 is a schematic diagram of an embodiment of the first DC-DC module shown in Figure 5;

Figure 7 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 8 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 9 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 10 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 11 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 12 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 13 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 14 is a schematic diagram of an embodiment of the switch unit shown in Figure 1;

Figure 15 is a schematic diagram of a preferred embodiment of the battery heating circuit provided in the present invention;

Figure 16 is a schematic diagram of an embodiment of the energy consumption unit shown in Figure 15;

Figure 17 is a schematic diagram of an embodiment of the battery heating circuit provided in the present invention;

Figure 18 is a timing sequence diagram of the waveform corresponding to the heating circuit shown in Figure 17;

Figure 19 is a schematic diagram of an embodiment of the battery heating circuit provided in the present invention; and

Figure 20 is a timing sequence diagram of the waveform corresponding to the heating circuit shown in Figure 19.

Detailed Description of the Embodiments

Hereafter the embodiments of the present invention will be elaborated in detail, with reference to the accompanying drawings. It should be appreciated that the embodiments described here are only provided to describe and explain the present invention, but shall not be deemed as constituting any limitation to the present invention.

It is noted that, unless otherwise specified, where mentioned hereafter in this description, the term "switching control module" refers to any controller that can output control commands (e.g., pulse waveform) under preset conditions or at preset times and thereby controls the switch unit connected to it to switch on or switch off accordingly, for example, the switching control module can be a Programmable Logic Controller (PLC); where mentioned hereafter in this description, the term "switch" refers to a switch that enables ON/OFF control by means of electrical signals or enables ON/OFF control on the basis of the characteristics of the element or component, which is to say, the switch can be either a one-way switch (e.g., a switch composed of a two-way switch and a diode connected in series, which can switch on in one direction) or a two-way switch (e.g., a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) or an Insulated Gate Bipolar Transistor (IGBT) with an anti-parallel freewheeling diode); where mentioned hereafter in this description, the term "two-way switch" refers to a switch that can switch on in two ways, which can enable ON/OFF control by means of electrical signals or enable ON/OFF control on the basis of the characteristics of the element or component, for example, the two-way switch can be a MOSFET or an IGBT with an anti-parallel freewheeling diode; where mentioned hereafter in this description, the term "one-way semiconductor element" refers to a semiconductor element that can switch on in one direction, such as an diode; where mentioned hereafter in this description, the term "charge storage element" refers to any device that can enable charge storage, such as a capacitor; where mentioned hereafter in this description, the term "current storage element" refers to any device that can store current, such as an inductor; where mentioned hereafter in this description, the term "forward direction" refers to the direction in which the energy flows from the battery to the energy storage circuit, and the term "reverse direction" refers to the direction in which the energy flows from the energy storage circuit to the battery; where mentioned hereafter in this description, the term "battery" comprises primary battery (e.g., dry battery or alkaline battery, etc.) and secondary battery (e.g., lithium-ion battery, nickel-cadmium battery, nickel-hydrogen battery, or lead-acid battery, etc.); where mentioned hereafter in this description, the term "damping element" refers to any device that inhibits current flow and thereby enables energy consumption, such as a resistor, etc.; where mentioned hereafter in this description, the term "main loop" refers to a loop composed of battery and damping element, switch unit and energy storage circuit connected in series.

It should be noted specially that in view different types of batteries have different characteristics, in the present invention, the "battery" may refer to an ideal battery that does not have internal parasitic resistance and parasitic inductance or has very low internal parasitic resistance and parasitic inductance, or may refer to a battery pack that has internal parasitic resistance and parasitic inductance; therefore, those skilled in the art should appreciate that if the battery is an ideal battery that does not have internal parasitic resistance and parasitic inductance or has very low internal parasitic resistance and parasitic inductance, the damping element R1 refers to a damping element external to the battery, and the current storage element L1 refers to a current storage element external to the battery; if the battery is a battery pack that has internal parasitic resistance and parasitic inductance, the damping element R1 refers to a damping element external to the battery, or refers to the parasitic resistance in the battery pack; likewise, the current storage element L2 refers to a current storage element external to the battery, or refers to the parasitic inductance in the battery pack.

To ensure the normal service life of the battery, the battery can be heated under low temperature condition, which is to say, when the heating condition is met, the heating circuit is controlled to start heating for the battery; when the heating stop condition is met, the heating circuit is controlled to stop heating.

In the actual application of battery, the battery heating condition and heating stop condition can be set according to the actual ambient conditions, to ensure normal charge/discharge performance of the battery.

To heat up a battery E in low temperature environment, as shown in Figure 1, the present invention provides a battery heating circuit, comprising a switch unit 1, a switching control module 100, a damping element R1, an energy storage circuit, and an energy superposition unit, wherein, the energy storage circuit is connected with the battery, and comprises a current storage element L1 and a charge storage element C1; the damping element R1, switch unit 1, current storage element L1, and charge storage element C1 are connected in series; the switching control module 100 is connected with the switch unit 1, and configured to control ON/OFF of the switch unit 1, so as to control the energy flowing between the battery and the energy storage circuit; the energy superposition unit is connected with the energy storage circuit, and is configured to superpose the energy in the energy storage circuit with the energy in the battery after the switch unit 1 switches on and then switches off.

With the technical solution of the present invention, when the heating condition is met, the switching control module 100 controls the switch unit 1 to switch on, and thus the battery E is connected with the energy storage circuit in series to form a loop, and can discharge through the loop (i.e., charge the charge storage element C1); when the current in the loop reaches to zero in forward direction after the peak current, the charge storage element C1 begins to discharge through the loop, i.e., charge the battery E; in the charge/discharge process of the battery E, the current in the loop always passes through the damping element R1, no matter whether the current flows in forward direction or reverse direction, and thus the battery E is heated up by the heat generated in the damping element R1; by controlling the ON/OFF time of the switch unit 1, the battery E can be controlled to heat up only in discharge mode or in both discharge mode and charge mode. When the heating stop condition is met, the switching control module 100 can control the switch unit 1 to switch off and thereby stop the operation of the heating circuit.

The energy superposition unit is connected with the energy storage circuit, and is configured to superpose the energy in the energy storage circuit with the energy in the battery E after the switch unit 1 switches on and then switches off, so that the discharging current in the heating loop will be increased when the switch unit 1 switches on again, and thereby the working efficiency of the heating circuit is improved.

In an embodiment of the present invention, as shown in Figure 2, the energy superposition unit comprises a polarity inversion unit 102, which is connected with the energy storage circuit, and is configured to invert the voltage polarity of the charge storage element C1 after the switch unit 1 switches on and then switches off. Since the voltage of the charge storage element C1 can be superposed in series with the voltage of the battery E after polarity inversion, the discharging current in the heating loop will be increased when the switch unit 1 switches on again.

As an embodiment of the polarity inversion unit 102, as shown in Figure 3, the polarity inversion unit 102 comprises a single pole double throw switch J1 and a single pole double throw switch J2 located on the two ends of the charge storage element C1 respectively; the input wires of the single pole double throw switch J1 are connected in the energy storage circuit, the first output wire of the single pole double throw switch J1 is connected with the first pole plate of the charge storage element C1, and the second output wire of the single pole double throw switch J1 is connected with the second pole plate of the charge storage element C1; the input wires of the single pole double throw switch J2 are connected in the energy storage circuit, the first output wire of the single pole double throw switch J2 is connected with the second pole plate of the charge storage element C1, and the second output wire of the single pole double throw switch J2 is connected with the first pole plate of the charge storage element C1; the switching control module 100 is also connected with the single pole double throw switch J1 and single pole double throw switch J2 respectively, and is configured to invert the voltage polarity of the charge storage element C1 by altering the connection relationships between the respective input wires and output wires of the single pole double throw switch J1 and the single pole double throw switch J2.

According to this embodiment, the connection relationships between the respective input wires and output wires of the single pole double throw switch J1 and single pole double throw switch J2 can be set in advance, so that the input wires of the single pole double throw switch J1 are connected with the first output wire of the single pole double throw switch J1 and the input wires of the single pole double throw switch J2 are connected with the first output wire of the single pole double throw switch J2 when the switch unit K1 switches on; the input wires of the single pole double throw switch J1 are switched to connect with the second output wire of the single pole double throw switch J1 and the input wires of the single pole double throw switch J2 are switched to connect with the second output wire of the single pole double throw switch J2 under control of the switching control module 100 when the switch unit K1 switches off, and thereby the voltage polarity of the charge storage element C1 is inverted.

As another embodiment of the polarity inversion unit 102, as shown in Figure 4, the polarity inversion unit 102 comprises a one-way semiconductor element D3, a current storage element L2, and a switch K9; the charge storage element C1, current storage element L2, and switch K9 are connected sequentially in series to form a loop; the one-way semiconductor element D3 is connected in series between the charge storage element C1 and the current storage element L2 or between the current storage element L2 and the switch K9; the switching control module 100 is also connected with the switch K9, and is configured to invert the voltage polarity of the charge storage element C1 by controlling the switch K9 to switch on.

According to the above embodiment, when the switch unit 1 switches off, the switch K9 can be controlled to switch on by the switching control module 100, and thereby the charge storage element C1, one-way semiconductor element D3, current storage element L2, and switch K9 form a LC oscillation loop, and the charge storage element C1 discharges through the current storage element L2, thus, the voltage polarity of the charge storage element C1 will be inverted when the current flowing through the current storage element L2 reaches to zero after the current in the oscillation circuit flows through the positive half cycle.

As yet another embodiment of the polarity inversion unit 102, as shown in Figure 5, the polarity inversion unit 102 comprises a first DC-DC module 2 and a charge storage element C2; the first DC-DC module 2 is connected with the charge storage element C1 and the charge storage element C2 respectively; the switching control module 100 is also connected with the first DC-DC module 2, and is configured to transfer the energy in the charge storage element C1 to the charge storage element C2 by controlling the operation of the first DC-DC module 2, and then transfer the energy in the charge storage element C2 back to the charge storage element C1, so as to invert the voltage polarity of the charge storage element C1.

The first DC-DC module 2 is a DC-DC（direct current to direct current） conversion circuit for voltage polarity inversion commonly used in the field. The present invention doesn't make any limitation to the specific circuit structure of the first DC-DC module 2, as long as the module can accomplish voltage polarity inversion of the charge storage element C1. Those skilled in the art can add, substitute, or delete the elements in the circuit as required.

Figure 6 shows an embodiment of the first DC-DC module 2 provided in the present invention. As shown in Figure 6, the first DC-DC module 2 comprises: a two-way switch Q1, a two-way switch Q2, a two-way switch Q3, a two-way switch Q4, a first transformer T1, an one-way semiconductor element D4, an one-way semiconductor element D5, a current storage element L3, a two-way switch Q5, a two-way switch Q6, a second transformer T2, an one-way semiconductor element D6, an one-way semiconductor element D7, and an one-way semiconductor element D8.

In the embodiment, the two-way switch Q1, two-way switch Q2, two-way switch Q3, and two-way switch Q4 are MOSFETs, and the two-way switch Q5 and two-way switch Q6 are IGBTs.

The Pin 1', 4', and 5' of the first transformer T1 are dotted terminals, and the pin 2' and 3' of the second transformer T2 are dotted terminals.

Wherein, the positive electrode of the one-way semiconductor element D7 is connected with the end 'a' of the charge storage element C1, and the negative electrode of the one-way semiconductor element D7 is connected with the drain electrodes of the two-way switch Q1 and two-way switch Q2, respectively; the source electrode of the two-way switch Q1 is connected with the drain electrode of the two-way switch Q3, and the source electrode of the two-way switch Q2 is connected with the drain electrode of the two-way switch Q4; the source electrodes of the two-way switch Q3 and two-way switch Q4 are connected with the end 'b' of the charge storage element C1 respectively. Thus, a full-bridge circuit is formed, here, the voltage polarity of end 'a' of the charge storage element C1 is positive, while the voltage polarity of end 'b' of the charge storage element C1is negative.

In the full-bridge circuit, the two-way switch Q1, two-way switch Q2 constitute the upper bridge arm, while the two-way switch Q3 and two-way switch Q4 constitute the lower bridge arm. The full-bridge circuit is connected with the charge storage element C2 via the first transformer T1; the pin 1' of the first transformer T1 is connected with the first node N1, the pin 2' of the first transformer T1 is connected with the second node N2, the pin 3' and pin 5' of the first transformer T1 are connected to the positive electrode of the one-way semiconductor element D4 and the positive electrode of the one-way semiconductor element D5 respectively; the negative electrode of one-way semiconductor element D4 and the negative electrode of one-way semiconductor element D5 are connected with one end of the current storage element L3, and the other end of the current storage element L3 is connected with the end 'd' of the charge storage element C2; the pin 4' of the transformer T1 is connected with the end 'c' of the charge storage element C2, the positive electrode of the one-way semiconductor element D8 is connected with the end 'd' of the charge storage element C2, and the negative electrode of the one-way semiconductor element D8 is connected with the end 'b' of the charge storage element C1; here, the voltage polarity of end 'c' of the charge storage element C2 is negative, while the voltage polarity of end 'd' of the charge storage element C2 is positive.

Wherein, the end 'c' of the charge storage element C2 is connected with the emitter electrode of the two-way switch Q5, the collector electrode of the two-way switch Q5 is connected with the pin 2' of the transformer T2, the pin 1' of the transformer T2 is connected with end 'a' of the charge storage element C1, the pin 4' of the transformer T2 is connected with end 'a' of the charge storage element C1, the pin 3' of the transformer T2 is connected with the positive electrode of the one-way semiconductor element D6, the negative electrode of the one-way semiconductor element D6 is connected with the collector electrode of the two-way switch Q6, and the emitter electrode of the two-way switch Q6 is connected with the end 'b' of the charge storage element C2.

Wherein, the two-way switch Q1, two-way switch Q2, two-way switch Q3, two-way switch Q4, two-way switch Q5, and two-way switch Q6 are controlled by the switching control module 100 respectively to switch on and switch off.

Hereafter the working process of the first DC-DC module 2 will be described:

1. After the switch unit 1 switches off, the switching control module 100 controls the two-way switch Q5 and two-way switch Q6 to switch off, and controls the two-way switch Q1 and two-way switch Q4 to switch on at the same time to form phase A; controls the two-way switch Q2 and two-way switch Q3 to switch on at the same time to form phase B. Thus, by controlling the phase A and phase B to switch on alternately, a full-bridge circuit is formed;

2. When the full-bridge circuit operates, the energy in the charge storage element C1 is transferred through the first transformer T1, one-way semiconductor element D4, one-way semiconductor element D5, and current storage element L3 to the charge storage element C2; now,

the voltage polarity of end 'c' of the charge storage element C2 is negative, while the voltage polarity of end 'd' of the charge storage element C2 is positive.

3. The switching control module 100 controls the two-way switch Q5 to switch on, and therefore a path from the charge storage element C1 to the charge storage element C2 is formed via the second transformer T2 and the one-way semiconductor element D8, thus, the

energy in the charge storage element C2 is transferred back to the charge storage element C1, wherein, some energy will be stored in the second transformer T2, Now, the switching control module 100 controls the two-way switch Q5 to switch off and controls the two-way switch Q6 to switch on, and therefore the energy stored in the second transformer T2 is transferred to the charge storage element C1 by the second transformer T2 and the one-way semiconductor element D6; now, the voltage polarity of the charge storage element C1 is inverted such that end 'a' is negative and end 'b' is positive. Thus, the purpose of inverting the voltage polarity of the charge storage element C1 is attained.

To prevent the charge storage element C1 from charging the battery E at low temperature and ensure the charge/discharge performance of the battery E, in a preferred embodiment of the heating circuit provided in the present invention, the switching control module 100 is configured to control ON/OFF of the switch unit 1, so as to control the energy to flow from the battery E to the energy storage circuit only, and thus the charging of battery E by the charge storage element C1 is prevented.

In order to control the energy to flow from the battery E to the charge storage element C1 only, in an embodiment of the present invention, as shown in Figure 7, the switch unit 1 comprises a switch K1 and a one-way semiconductor element D1, wherein, the switch K1 and the one-way semiconductor element D1 are connected with each other in series, and then connected in series in the energy storage circuit; the switching control module 100 is connected with the switch K1, and is configured to control ON/OFF of the switch unit 1 by controlling ON/OFF of the switch K1. By connecting a one-way semiconductor element D1 in series in the circuit, energy backflow from the charge storage element C1 can be prevented, and thereby charging of battery E can be avoided in case the switch K1 fails.

As for the embodiment in which the energy flows from the battery E to the charge storage element C1 only, the switching control module 100 is configured to control the switch unit 1 to switch off when or before the current flow through the switch unit 1 reaches to zero after the switch unit 1 switches on, as long as the current is controlled to flow from the battery E to the charge storage element C1 only.

Since the current drop rate is very high when the switch K1 switches off, high over-voltage will be induced on the current storage element L1 and may cause damage to the switch K1 because the current and voltage are beyond the safe working range. Therefore, preferably the switching control module 100 is configured to control the switch K1 to switch off when the current flow through the switch unit 1 reaches to zero after the switch unit 1 switches on.

To improve heating efficiency, preferably, in another embodiment of the present invention, as shown in Figure 8, the switching control module 100 is configured to control the switch unit 1 to switch off before the current flow through the switch unit 1 reaches to zero after the switch unit 1 switches on; the switch unit 1 comprises a one-way semiconductor element D9, a one-way semiconductor element D10, a switch K2, a damping element R4, and a charge storage element C3, wherein, the one-way semiconductor element D9 and the switch K2 are connected in series in the energy storage circuit, the damping element R4 and the charge storage element C3 are connected in series, and then connected in parallel across the switch K2; the one-way semiconductor element D10 is connected in parallel across the damping element R4, and is configured to sustain the current to the current storage element L1 when the switch K2 switches off; the switching control module 100 is connected with the switch K2, and is configured to control ON/OFF of the switch unit 1 by controlling ON/OFF of the switch K2.

The one-way semiconductor element D10, damping element R4, and charge storage element C3 constitute an absorption loop, which is configured to reduce the current drop rate in the energy storage circuit when the switch K2 switches off. Thus, when the switch K2 switches off, the induced voltage generated on the current storage element L1 will force the one-way semiconductor element D10 to switch on and enables current freewheeling with the charge storage element C3, so as to reduce the current change rate in the current storage element L1 and to suppress the induced voltage across the current storage element L1, to ensure the voltage across the switch K2 is within the safe working range. When the switch K2 switches on again, the energy stored in the charge storage element C3 can be consumed through the damping element R4.

In order to improve the working efficiency of the heating circuit, the energy can be controlled to flow to and fro between the battery E and the energy storage circuit, so as to utilize current flow through the damping element R1 in both forward direction and reverse direction to enable heating.

Therefore, in a preferred embodiment of the heating circuit provided in the present invention, the switching control module 100 is configured to control ON/OFF of the switch unit 1, so that the energy flows to and fro between the battery E and the energy storage circuit when the switch unit 1 is in ON state.

To enable energy flow to-and-fro between the battery E and the energy storage circuit, in an embodiment of the present invention, the switch unit 1 is a two-way switch K3; as shown in Figure 9, the switching control module 100 controls ON/OFF of the two-way switch K3, i.e., when the battery E needs to be heated, the two-way switch K3 can be controlled to switch on, when heating is to be paused or is not required, the two-way switch K3 can be controlled to switch off.

Employing a separate two-way switch K3 to implement the switch unit 1 can simplify the circuit, reduce system footprint, and facilitate the implementation; however, to implement cut-off of reverse current, the following preferred embodiment of the switch unit 1 is further provided in the present invention.

Preferably, the switch unit 1 comprises a first one-way branch configured to enable energy flow from the battery E to the energy storage circuit, and a second one-way branch configured to enable energy flow from the energy storage circuit to the battery E; wherein, the switching control module 100 is connected to either or both of the first one-way branch and second one-way branch, to control ON/OFF of the connected branches.

When the battery needs to be heated, both the first one-way branch and the second one-way branch can be controlled to switch on; when heating needs to be paused, either or both of the first one-way branch and the second one-way branch can be controlled to switch off; when heating is not required, both of the first one-way branch and the second one-way branch can be controlled to switch off. Preferably, both of the first one-way branch and the second one-way branch are subject to the control of the switching control module 100; thus, energy flow cut-off in forward direction and reverse direction can be implemented flexibly.

In another embodiment of the switch unit 1, as shown in Figure 10, the switch unit 1 may comprise a two-way switch K4 and a two-way switch K5, wherein, the two-way switch K4 and the two-way switch K5 are connected in series opposite to each other, to form the first one-way branch and the second one-way branch; the switching control module 100 is connected with the two-way switch K4 and the two-way switch K5 respectively, to control ON/OFF of the first one-way branch and the second one-way branch by controlling ON/OFF of the two-way switch K4 and two-way switch K5.

When the battery E needs to be heated, the two-way switches K4 and K5 can be controlled to switch on; when heating needs to be paused, either or both of the two-way switch K4 and the two-way switch K5 can be controlled to switch off; when heating is not required, both of the two-way switch K4 and the two-way switch K5 can be controlled to switch off. In such an implementation of switch unit 1, the first one-way branch and the second one-way branch can be controlled separately to switch on or off, and therefore energy flow cut-off in forward direction and reverse direction in the circuit can be implemented flexibly.

In another embodiment of switch unit 1, as shown in Figure 11, the switch unit 1 may comprise a switch K6, a one-way semiconductor element D11, and a one-way semiconductor element D12, wherein, the switch K6 and the one-way semiconductor element D11 are connected in series with each other to form the first one-way branch; the one-way semiconductor element D12 forms the second one-way branch; the switching control module 100 is connected with the switch K6, to control ON/OFF of the first one-way branch by controlling ON/OFF of the switch K6. In the switch unit 1 shown in Figure 11, when heating is required, the switch K6 can be controlled to switch on; when heating is not required, the switch K6 can be controlled to switch off.

Though the implementation of switch unit 1 shown in Figure 11 enables to-and-fro energy flow along separate branches, it cannot enable energy flow cut-off function in reverse direction. The present invention further puts forward another embodiment of switch unit 1; as shown in Figure 12, the switch unit 1 can further comprise a switch K7 in the second one-way branch, wherein, the switch K7 is connected with the one-way semiconductor element D12 in series, the switching control module 100 is also connected with the switch K7, and is configured to control ON/OFF of the second one-way branch by controlling ON/OFF of the switch K7. Thus, in the switch unit 1 shown in Figure 12, since there are switches (i.e., switch K6 and switch K7) in both one-way branches, energy flow cut-off function in forward direction and reverse direction is enabled simultaneously.

Preferably, the switch unit 1 can further comprise a resistor, which is connected in series with the first one-way branch and/or the second one-way branch and is configured to reduce the current in the heating circuit for the battery E and to avoid damage to the battery

E resulted from over-current in the circuit. For example, a resistor R6 connected in series with the two-way switch K4 and the two-way switch K5 can be added in the switch unit 1 shown in Figure 10, to obtain another implementation of the switch unit 1, as shown in Figure 13. Figure 14 also shows an embodiment of the switch unit 1, which is obtained by connecting respectively resistor R2 and resistor R3 in series in both the one-way branches in the switch unit 1 shown in Figure 12.

In an embodiment in which the energy flows to and fro between the battery E and the energy storage circuit, the switch unit 1 can be controlled to switch off at any point of time in one or more cycles, which is to say, the switch unit 1 can switch off at any time, for example, the switch unit 1 can switch off when the current flows through the switch unit 1 in forward direction or reverse direction, and is equal to zero or not equal to zero. A specific implementation form of the switch unit 1 can be selected, depending on the required cut-off strategy; if current flow cut-off in forward direction is only required, the implementation form of the switch unit 1 shown in Figure 9 or Figure 11 can be selected; if current flow cut-off in both forward direction and reverse direction is required, the switch unit with two controllable one-way branches shown in Figure 10 or Figure 12 can be selected.

Preferably, the switching control module 100 is configured to control the switch unit 1 to switch off when or after the current flow through the switch unit 1 reaches to zero after the switch unit 1 switches on. More preferably, the switching control module 100 is configured to control the switch unit 1 to switch off when the current flow through the switch unit 1 reaches to zero after the switch unit 1 switches on, so as to minimize the adverse effect to the entire circuit.

In an embodiment of the present invention, the working efficiency of the heating circuit can be improved by superposing the energy in the charge storage element C1 with the energy in the battery E directly, or superposing the remaining energy in the charge storage element C1 with the energy in the battery E after some energy in the charge storage element C1 is consumed.

Therefore, as shown in Figure 15, the heating circuit further comprises an energy consumption unit, which is connected with the charge storage element C1 and is configured to consume the energy in the charge storage element C1 after the switch unit 1 switches on and then switches off and before the energy in the energy superposition unit is superposed.

The energy consumption unit can be combined with the embodiments described above, including the embodiments in which the energy flows from the battery E to the energy storage circuit only, and the embodiments in which the energy flows to and fro between the battery E and the energy storage circuit.

In an embodiment of the present invention, as shown in Figure 16, the energy consumption unit comprises a voltage control unit 101, which is configured to convert the voltage across the charge storage element C1 to a predetermined value of voltage after the switch unit 1 switches on and then switches off and before the energy superposition unit performs energy superposition. The preset value of voltage can be set as required.

In an embodiment of the present invention, as shown in Figure 16, the voltage control unit 101 comprises a damping element R5 and a switch K8, wherein, the damping element R5 and switch K8 are connected with each other in series, and then connected in parallel across the charge storage element C1; the switching control module 100 is also connected with the switch K8, and is configured to control the switch K8 to switch on after the switch unit 1 switches on and then switches off. Thus, the energy in the charge storage element C1 can be consumed across the damping element R5.

The switching control module 100 can be a separate controller, which, by means of internal program setting, enables ON/OFF control of different external switches; or, the switching control module 100 can be a plurality of controllers, for example, a switching control module 100 can be set for each external switch correspondingly; or, the plurality of switching control modules 100 can be integrated into an assembly. The present invention does not define any limitation to the forms of implementation of the switching control module 100.

Hereafter the working principle of the embodiments of heating circuit for battery E will be described briefly with reference to Figures 17-20. It should be noted that though the features and elements of the present invention are described specifically with reference to Figures 17-20, each feature or element of the present invention can be used separately without other features and elements, or can be used in combination or not in combination with other features and elements. The embodiments of the heating circuit for battery E provided in the present invention are not limited to those shown in Figures 17-20. In addition, the grid part of the wave pattern indicates drive pulses can be applied to the switch more times within the period, and the pulse width can be adjusted as required.

In the heating circuit for battery E shown in Figure 17, the switch K1 and one-way semiconductor element D1 constitute the switch unit 1, and the energy storage circuit comprises a current storage element L1 and a charge storage element C1, wherein, the damping element R1 and switch unit 1 are connected in series with the energy storage circuit; the one-way semiconductor element D3, current storage element L2, and switch K9 constitute a polarity inversion unit 102 in the energy superposition unit; the switching control module 100 can control the switch K1 and switch K9 to switch on and switch off. Figure 18 is a timing sequence diagram of the waveform corresponding to the heating circuit shown in Figure 17, wherein, VC1 refers the voltage value across the charge storage element C1, and Imain refers to the value of current flow through the switch K1. The working process of the heating circuit is as follows:

a) When the battery E is to be heated, the switching control module 100 controls the switch K1 to switch on, and thereby the battery E discharges through the loop composed of the switch K1, one-way semiconductor element D1, and charge storage element C1, as indicated by the time duration t1 shown in Figure 18; when the current flowing through the switch K1 is zero, the switching control module 100 controls the switch K1 to switch off, as indicated by the time duration t2 shown in Figure 18;

b) After the switch K1 switches off, the switching control module 100 controls the switch K9 to switch on, and thereby the charge storage element C1 discharges through the loop composed of the one-way semiconductor element D3, current storage element L2, and switch K9, so as to attain the purpose of voltage polarity inversion, and then, the switching control module 100 controls the switch K9 to switch off, as indicated by the time duration t2 shown in Figure 18.

c) Repeat step a) and step b), the battery E is heated up continuously while it discharges, till the heating stop condition is met.

In the heating circuit for battery E shown in Figure 19, a two-way switch K3 is used to form the switch unit 1, the energy storage circuit comprises a current storage element L1 and a charge storage element C1, the damping element R1 and switch unit 1 are connected in series with the energy storage circuit, the one-way semiconductor element D3, current storage element L2, and switch K9 constitute a polarity inversion unit 102, and the switching control module 100 can control the switch K9 and two-way switch K3 to switch on and switch off. Figure 20 is a timing sequence diagram of the waveform corresponding to the heating circuit shown in Figure 19, wherein, VC1 refers the voltage value across the charge storage element C1, Imain refers to the value of current flowing through the two-way switch K3, and IL2 refers to the value of current in the polarity inversion loop. The working process of the heating circuit shown in Figure 19 is as follows:

a) The switching control module 100 controls the two-way switch K3 to switch on, and therefore the energy storage circuit starts to operate, as indicated by the time duration t1 shown in Figure 20; the battery E discharges in forward direction through the loop composed of the two-way switch K3 and charge storage element C1 (as indicated by the time duration t1 shown in Figure 20, i.e., the positive half cycle of the current flowing through the two-way switch K3) and is charged in reverse direction (as indicated by the time duration t1 shown in Figure 20, i.e., the negative half cycle of the current flowing through the two-way switch K3);

b) The switching control module 100 controls the two-way switch K3 to switch off when the current in reverse direction is zero;

c) The switching control module 100 controls the switch K9 to switch on, and therefore the polarity inversion unit 102 starts to operate; the charge storage element C1 discharges through the loop composed by the semiconductor element D3, current storage element L2, and switch K9, to attain the purpose of voltage polarity inversion; then, the switching control module 100 controls the switch K9 to switch off, as indicated by the time duration t2 shown in Figure 20.

d) Repeat step a) to step c), the battery E is heated up continuously while it discharges and is charged, till the battery E meets the heating stop condition.

The heating circuit provided in the present invention can improve the charge/discharge performance of a battery. In addition, since an energy storage circuit is connected with the battery in series in the heating circuit, the safety problem related with short circuit caused by failures of the switch unit can be avoided when the battery is heated due to the existence of the charge storage element connected in series, and therefore the battery can be protected effectively. In addition, an energy superposition unit is provided in the heating circuit in the present invention, and the energy superposition unit can superpose the energy in the energy storage circuit with the energy in the battery after the switch unit switches on and then switches off, thus, the discharging current in the heating loop will be increased when the switch unit is controlled to switch on at the next time, and therefore the working efficiency of the heating circuit is improved.

While some preferred embodiments of the present invention are described above with reference to the accompanying drawings, the present invention is not limited to the details in those embodiments. Those skilled in the art can make modifications and variations to the technical solution of the present invention, without departing from the present invention. However, all these modifications and variations shall be deemed as falling into the scope of the present invention.

In addition, it should be noted that the specific technical features described in above embodiments can be combined in any appropriate form, provided that there is no conflict. To avoid unnecessary repetition, the possible combinations are not described specifically in the present invention. Moreover, the different embodiments of the present invention can be combined freely as required, as long as the combinations do not deviate from the ideal of the present invention. However, such combinations shall also be deemed as falling into the scope disclosed in the present invention.

Claims

1. A battery heating circuit, comprising a switch unit, a switching control module, a damping element , an energy storage circuit, and an energy superposition unit, wherein, the energy storage circuit is connected with the battery, and comprises a first current storage element and a first charge storage element; the damping element, switch unit, first current storage element, and first charge storage element are connected in series; the switching control module is connected with the switch unit, and configured to control ON/OFF of the switch unit, so as to control the energy flowing between the battery and the energy storage circuit; and the energy superposition unit is connected with the energy storage circuit, and is configured to superpose the energy in the energy storage circuit with the energy in the battery after the switch unit switches on and then switches off.

2. The heating circuit according to Claim 1, wherein, the damping element is a parasitic resistance in the battery, and the first current storage element is a parasitic inductance in the battery.

3. The heating circuit according to claim 2, wherein, the energy superposition unit comprises a polarity inversion unit, which is connected with the energy storage circuit, and configured to invert the voltage polarity of the first charge storage element after the switch unit switches on and then switches off.

4. The heating circuit according to claim 3, wherein, the polarity inversion unit comprises a first single pole double throw switch and a second single pole double throw switch located on two ends of the first charge storage element respectively; input wires of the first single pole double throw switch are connected in the energy storage circuit, a first output wire of the first single pole double throw switch is connected with a first pole plate of the first charge storage element, and a second output wire of the first single pole double throw switch is connected with a second pole plate of the first charge storage element; input wires of the second single pole double throw switch are connected in the energy storage circuit, a first output wire of the second single pole double throw switch is connected with

the second pole plate of the first charge storage element, and a second output wire of the second single pole double throw switch is connected with the first pole plate of the first charge storage element; and the switching control module is also connected with the first single pole double throw switch and second single pole double throw switch respectively, and is configured to invert the voltage polarity of the first charge storage element by altering the connection relationships between the respective input wires and output wires of the first single pole double throw switch and the second single pole double throw switch.

5. The heating circuit according to claim 3, wherein, the polarity inversion unit comprises a one-way semiconductor element, a second current storage element, and a switch; the first charge storage element, second current storage element, and switch are connected sequentially in series to form a loop; the one-way semiconductor element is connected in series between the first charge storage element and the second current storage element or between the second current storage element and the switch; and the switching control module is also connected with the switch, and is configured to invert the voltage polarity of the first charge storage element by controlling the switch to switch on.

6. The heating circuit according to claim 3, wherein, the polarity inversion unit comprises a first DC-DC module and a second charge storage element; the first DC-DC module is connected with the first charge storage element and the second charge storage element respectively; and the switching control module is also connected with the first DC-DC module, and is configured to transfer the energy in the first charge storage element to the second charge storage element by controlling the operation of the first DC-DC module, and then transfer the energy in the second charge storage element back to the first charge storage element, so as to invert the voltage polarity of the first charge storage element.

7. The heating circuit according to claim 2, wherein, the switching control module is configured to control ON/OFF of the switch unit, so as to control the energy to flow from the battery to the energy storage circuit only.

8. The heating circuit according to Claim 7, wherein, the switch unit comprises a

switch and a one-way semiconductor element, the switch and the one-way semiconductor element are connected with each other in series, and then connected in the energy storage circuit in series; and the switching control module is connected with the switch, and configured to control ON/OFF of the switch unit by controlling ON/OFF of the switch.

9. The heating circuit according to Claim 7, wherein, the switching control module is configured to control the switch unit to switch off when or before the current flow through the switch unit reaches to zero after the switch unit switches on.

10. The heating circuit according to Claim 9, wherein, the switching control module is configured to control the switch unit to switch off before the current flow through the switch unit reaches to zero after the switch unit switches on; the switch unit comprises a first one-way semiconductor element, a second one-way semiconductor element, a switch, a resistor, and a second charge storage element; the first one-way semiconductor element and the switch are connected in series in the energy storage circuit, the resistor and the second charge storage element are connected with each other in series and then connected across the switch in parallel; the second one-way semiconductor element is connected in parallel across the resistor, and is configured to sustain the current flow through the first current storage element when the switch switches off; and the switching control module is connected with the switch, and is configured to control ON/OFF of the switch unit by controlling ON/OFF of the switch.

11. The heating circuit according to Claim 2, wherein, the switching control module is configured to control ON/OFF of the switch unit, so that the energy flows to and fro between the battery and the energy storage circuit when the switch unit switches on.

12. The heating circuit according to Claim 11, wherein, the switch unit is a two-way switch.

13. The heating circuit according to Claim 11, wherein, the switch unit comprises a first one-way branch configured to enable energy flow from the battery to the energy storage

circuit and a second one-way branch configured to enable energy flow from the energy storage circuit to the battery; the switching control module is connected to either or both of the first one-way branch and second one-way branch, and is configured to control ON/OFF of the switch unit by controlling ON/OFF of the connected branches.

14. The heating circuit according to Claim 13, wherein, the switch unit further comprises a first two-way switch and a second two-way switch, the first two-way switch and the second two-way switch are connected in series opposite to each other to form the first one-way branch and the second one-way branch; and the switching control module is connected with the first two-way switch and second two-way switch respectively, and is configured to control ON/OFF of the first one-way branch and second one-way branch by controlling ON/OFF of the first two-way switch and second two-way switch.

15. The heating circuit according to Claim 13, wherein, the switch unit further comprises a first switch, a first one-way semiconductor element, and a second one-way semiconductor element, the switch and the first one-way semiconductor element are connected with each other in series to constitute the first one-way branch; the second one-way semiconductor element constitutes the second one-way branch; and the switching control module is connected with the first switch, and is configured to control ON/OFF of the first one-way branch by controlling ON/OFF of the first switch.

16. The heating circuit according to Claim 15, wherein, the switch unit further comprises a second switch in the second one-way branch, and the second switch is connected with the second one-way semiconductor element in series; and the switching control module is further connected with the second switch, and is configured to control ON/OFF of the second one-way branch by controlling ON/OFF of the second switch.

17. The heating circuit according to Claim 11, wherein, the switching control module is configured to control the switch unit to switch off when or after the current flow through the switch unit reaches to zero after the switch unit switches on.

18. The heating circuit according to any one of claims 1-17, wherein, the heating circuit further comprises an energy consumption unit, which is connected with the first charge storage element, and is configured to consume the energy in the first charge storage element after the switch unit switches on and then switches off and before the energy superposition unit performs energy superposition; and the energy consumption unit comprises a voltage control unit, which is connected with the first charge storage element, and is configured to convert the voltage value across the first charge storage element to a predetermined voltage value after the switch unit switches on and then switches off and before the energy superposition unit performs energy superposition.

19. The heating circuit according to Claim 18, wherein, the voltage control unit comprises a damping element and a switch connected with each other in series, and then connected in parallel across the first charge storage element; and the switching control module is further connected with the switch of the voltage control unit, and is configured to control the switch of the voltage control unit to switch on after the switch unit switches on and then switches off.

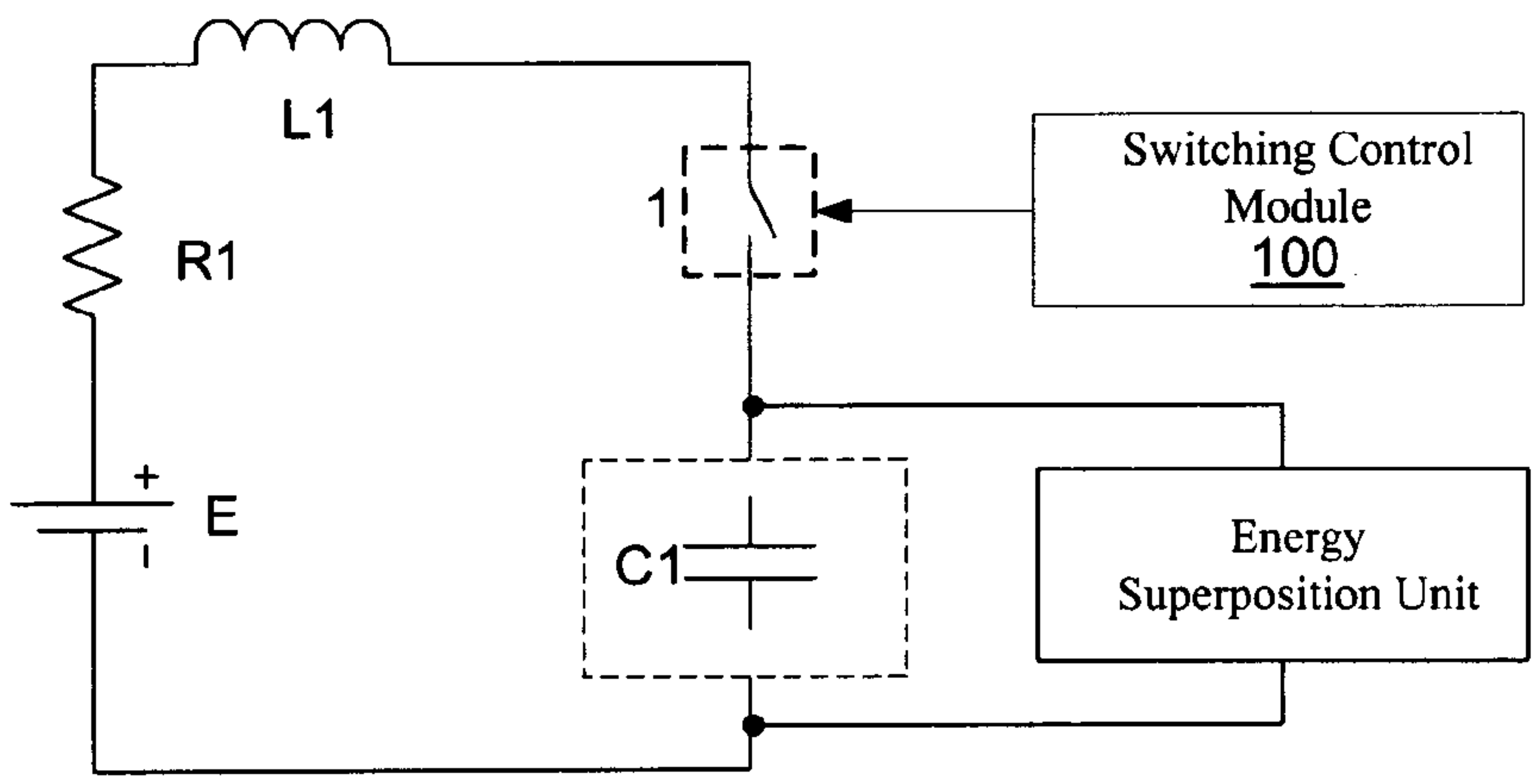


Figure 1

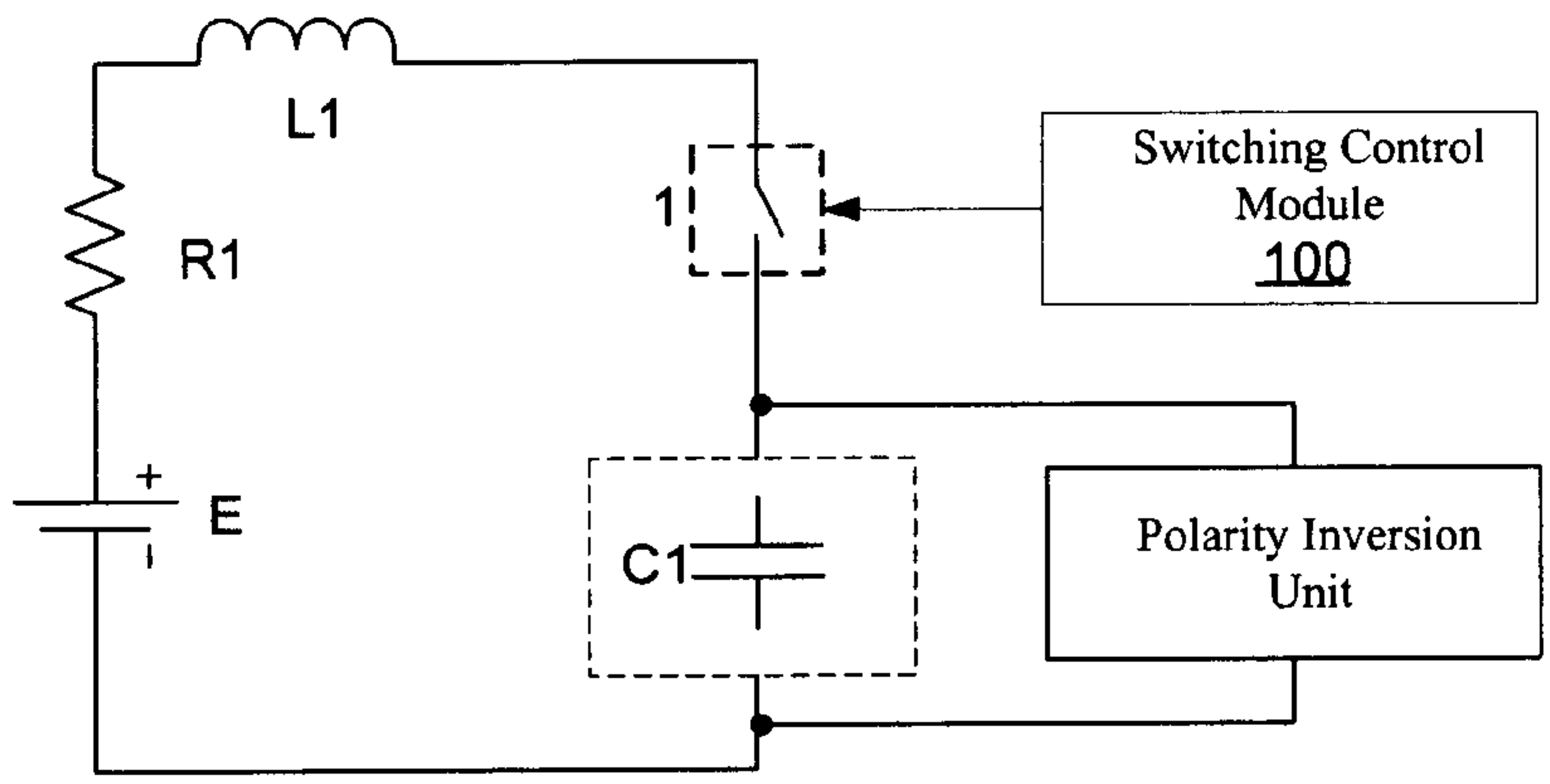


Figure 2

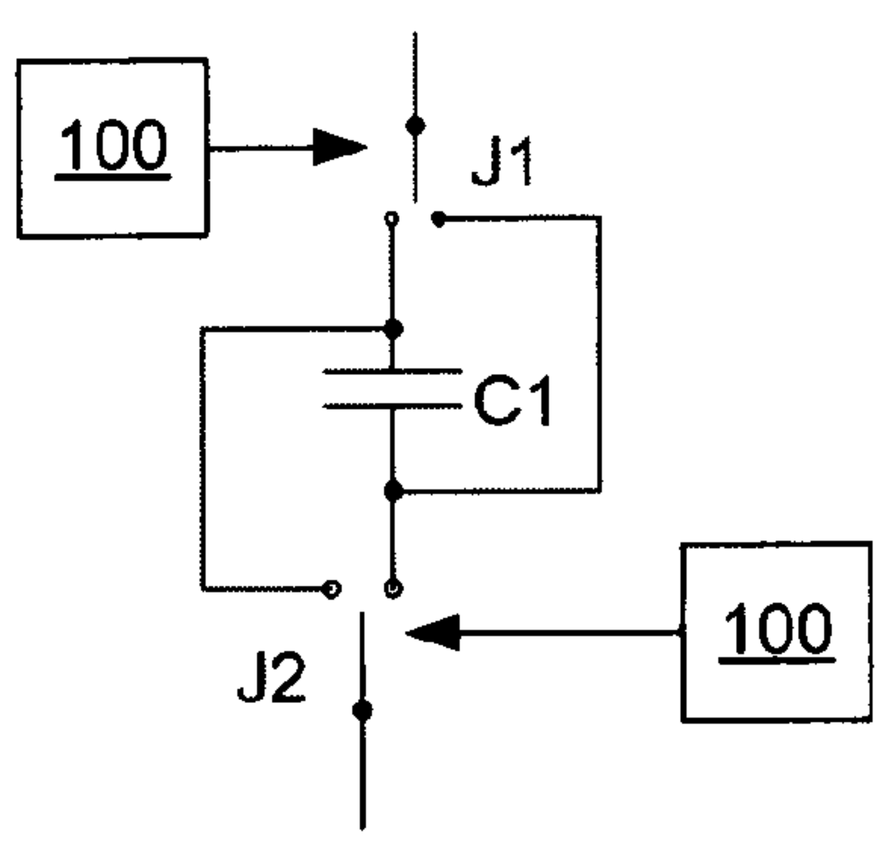


Figure 3

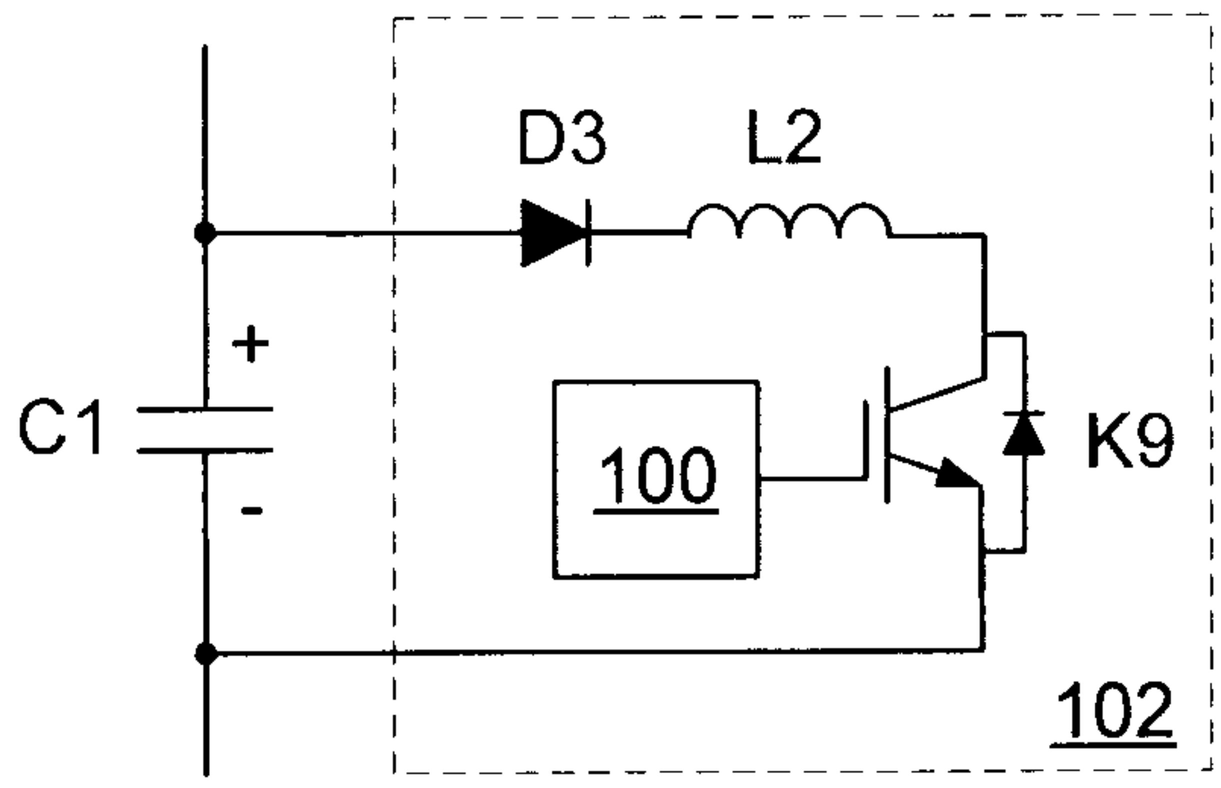


Figure 4

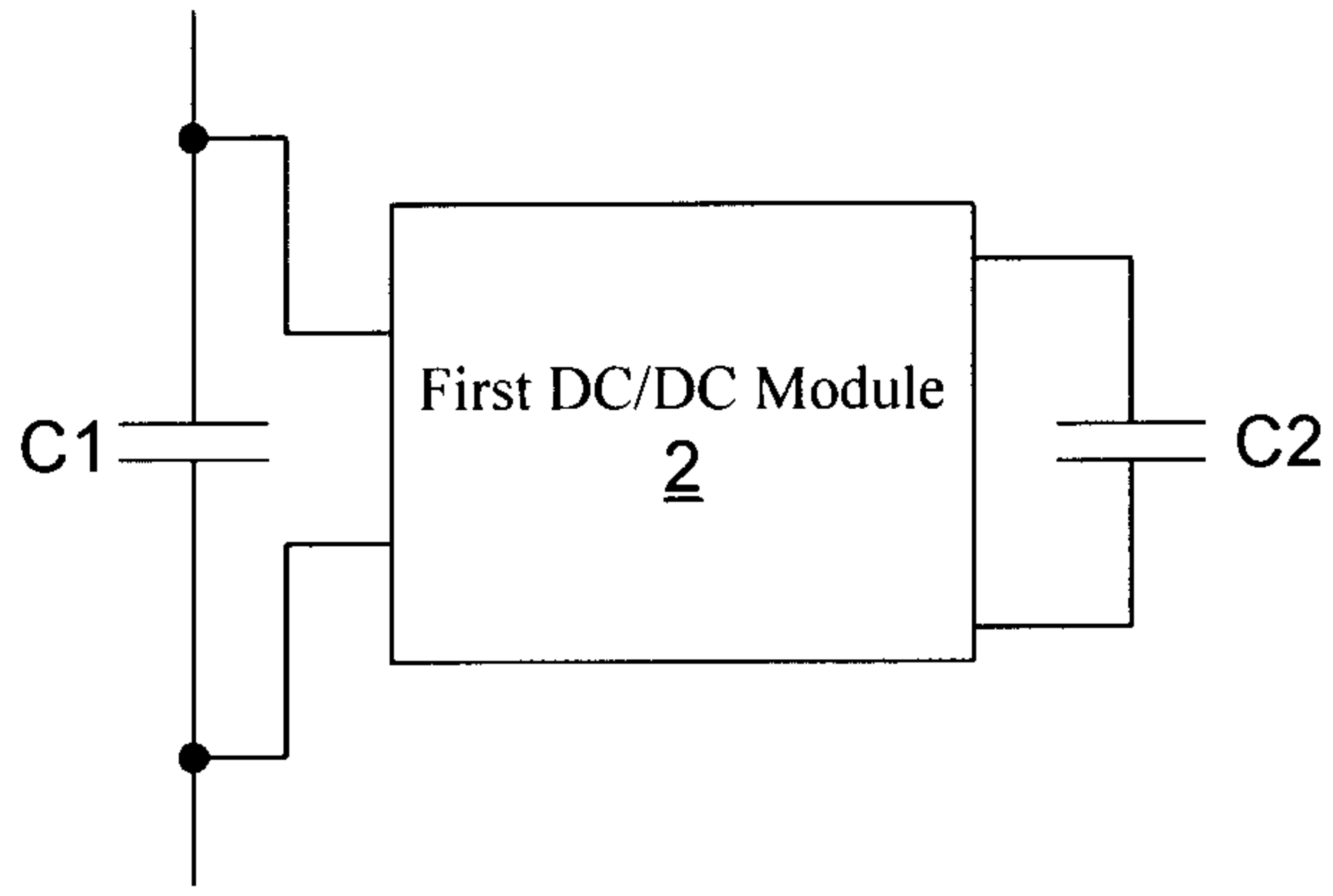


Figure 5

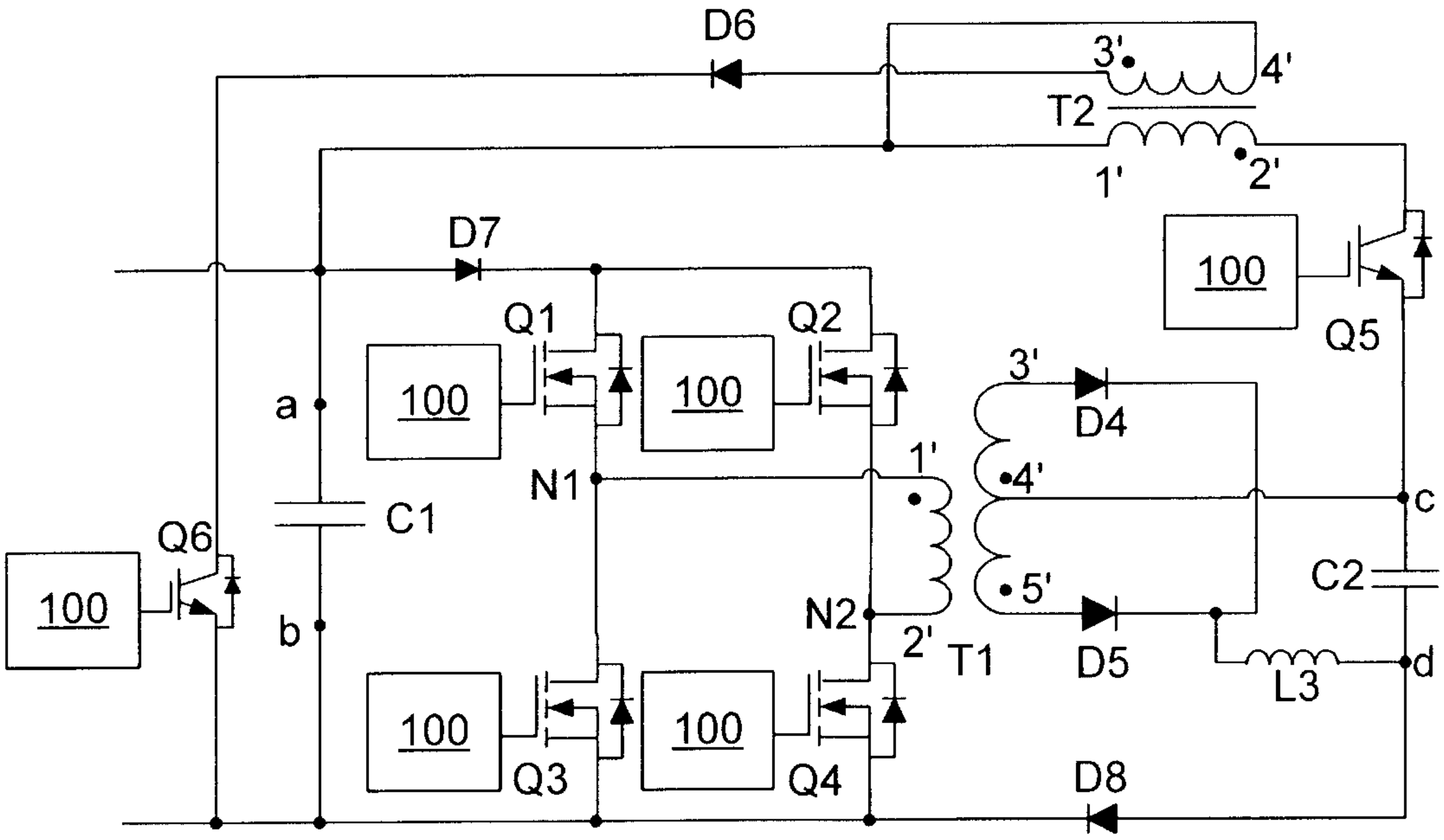


Figure 6

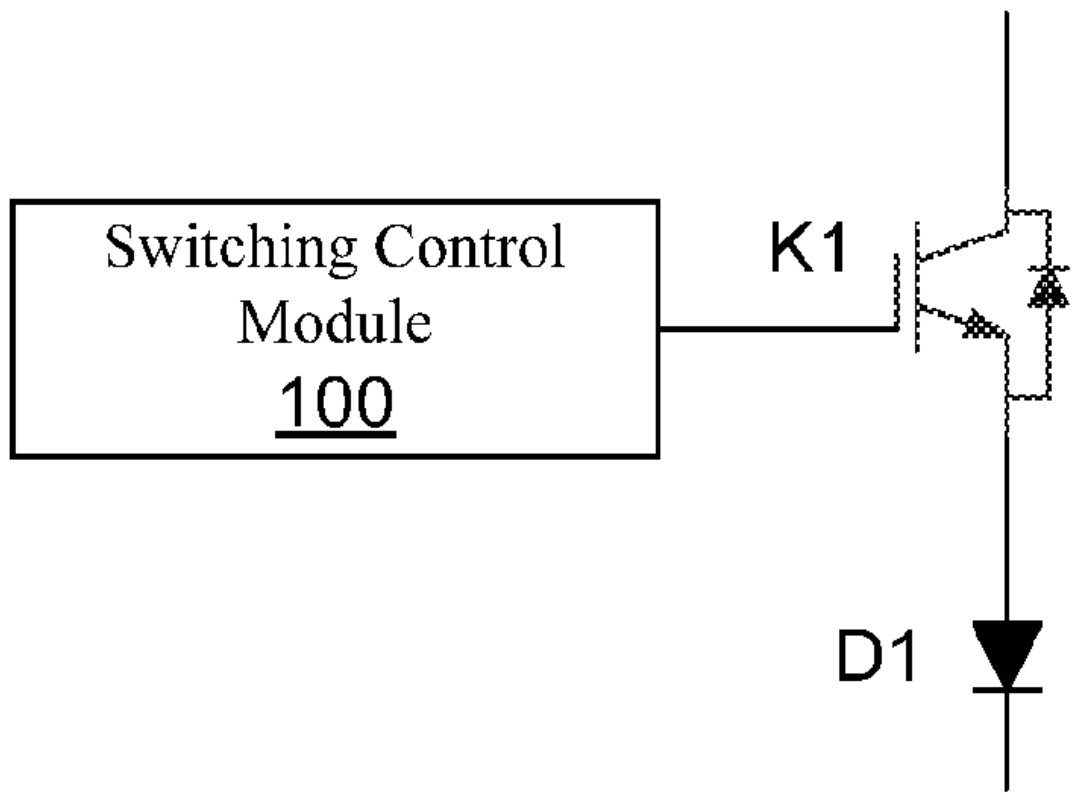


Figure 7

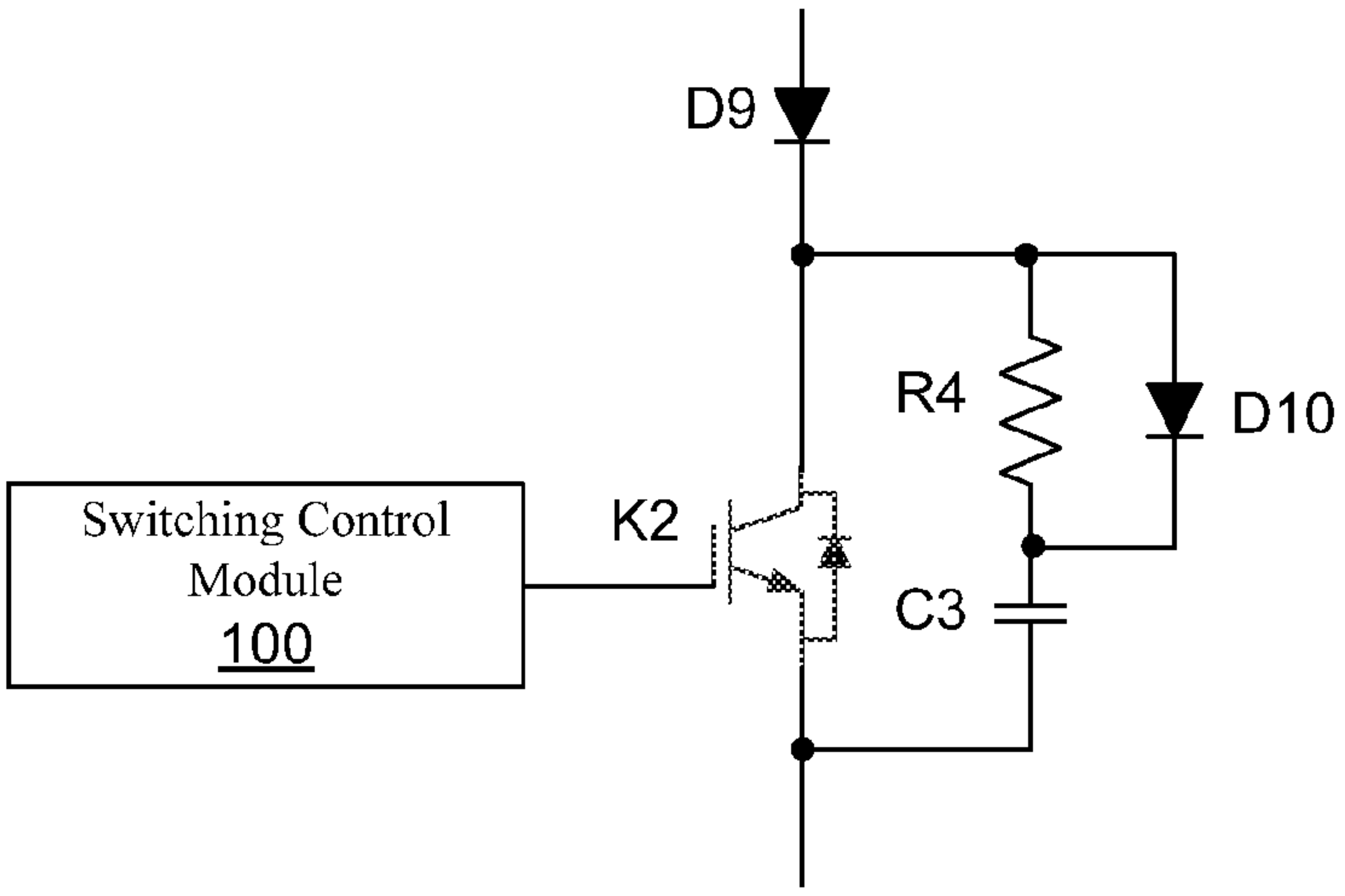


Figure 8

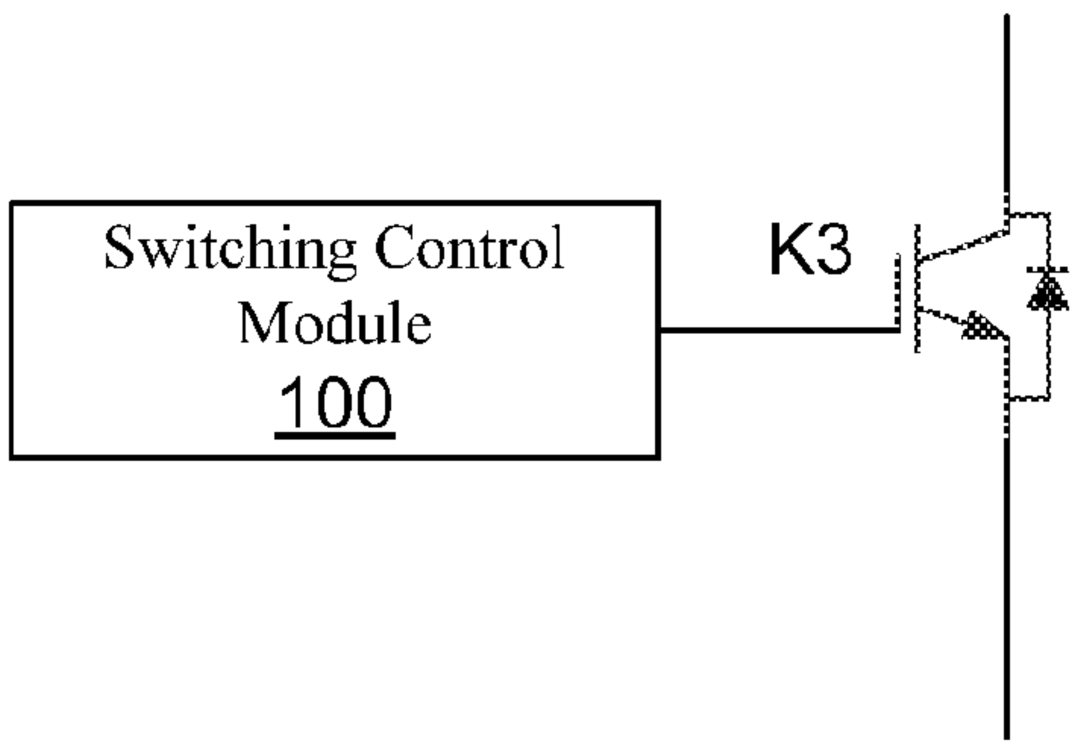


Figure 9

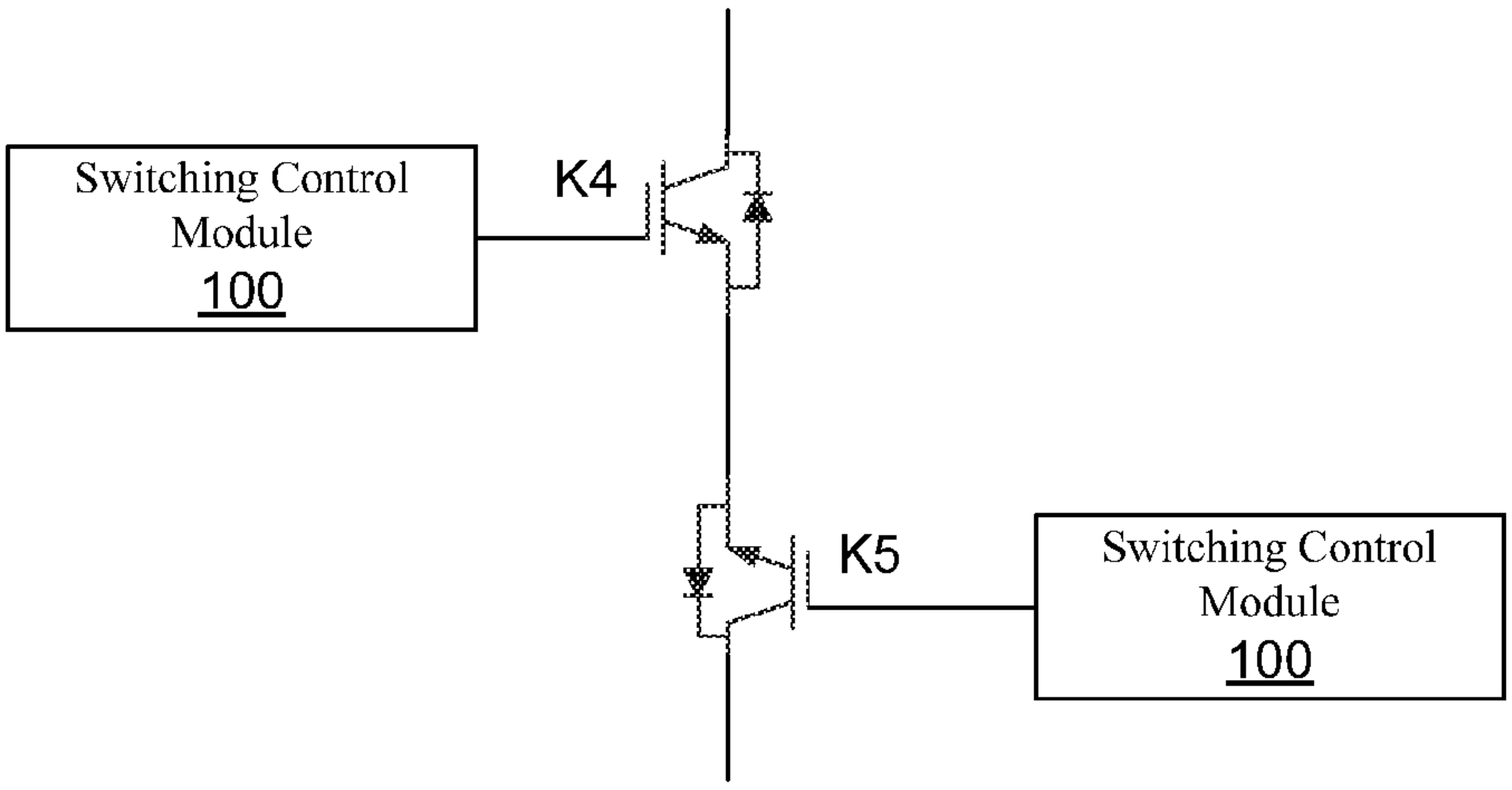


Figure 10

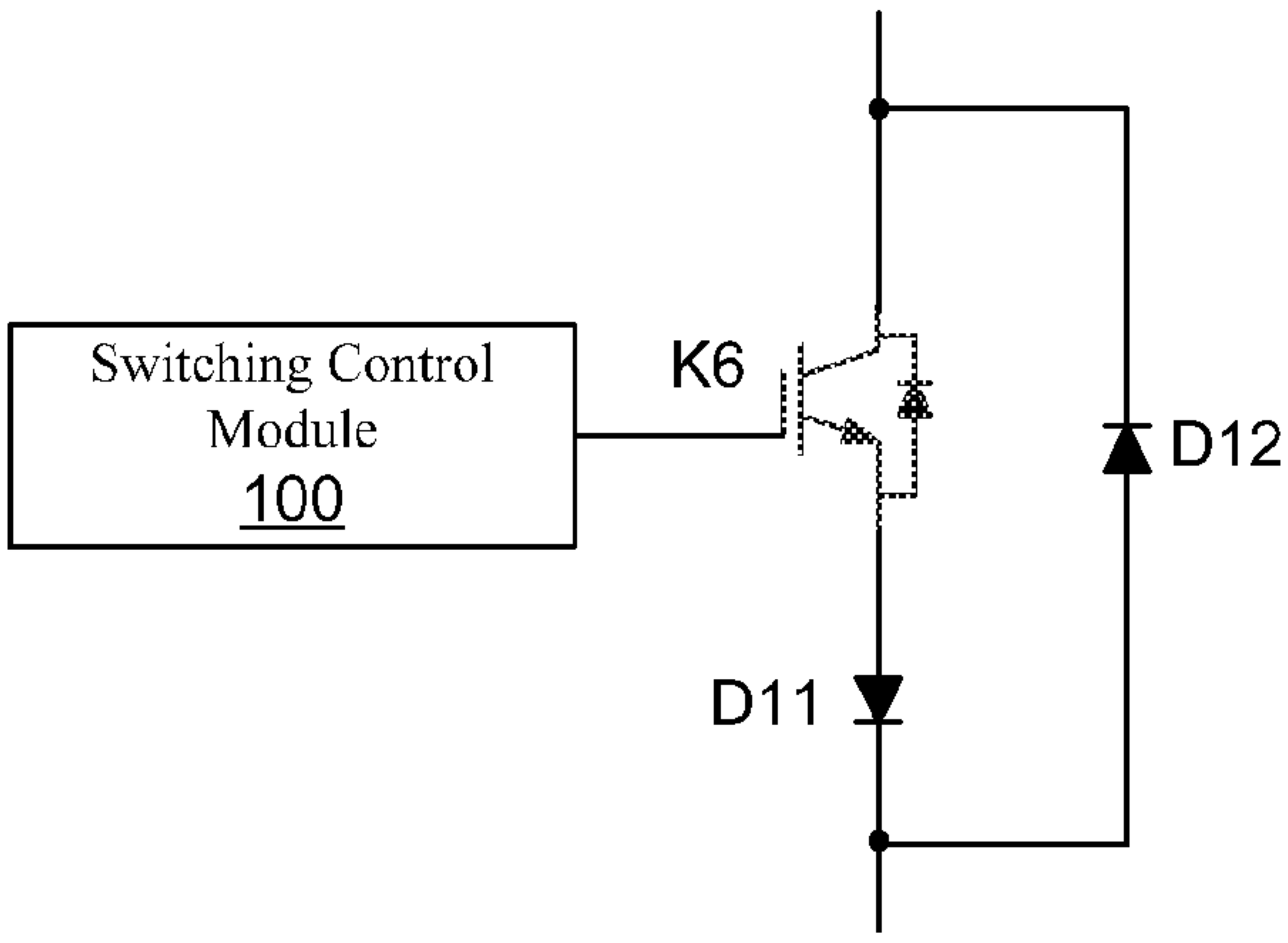


Figure 11

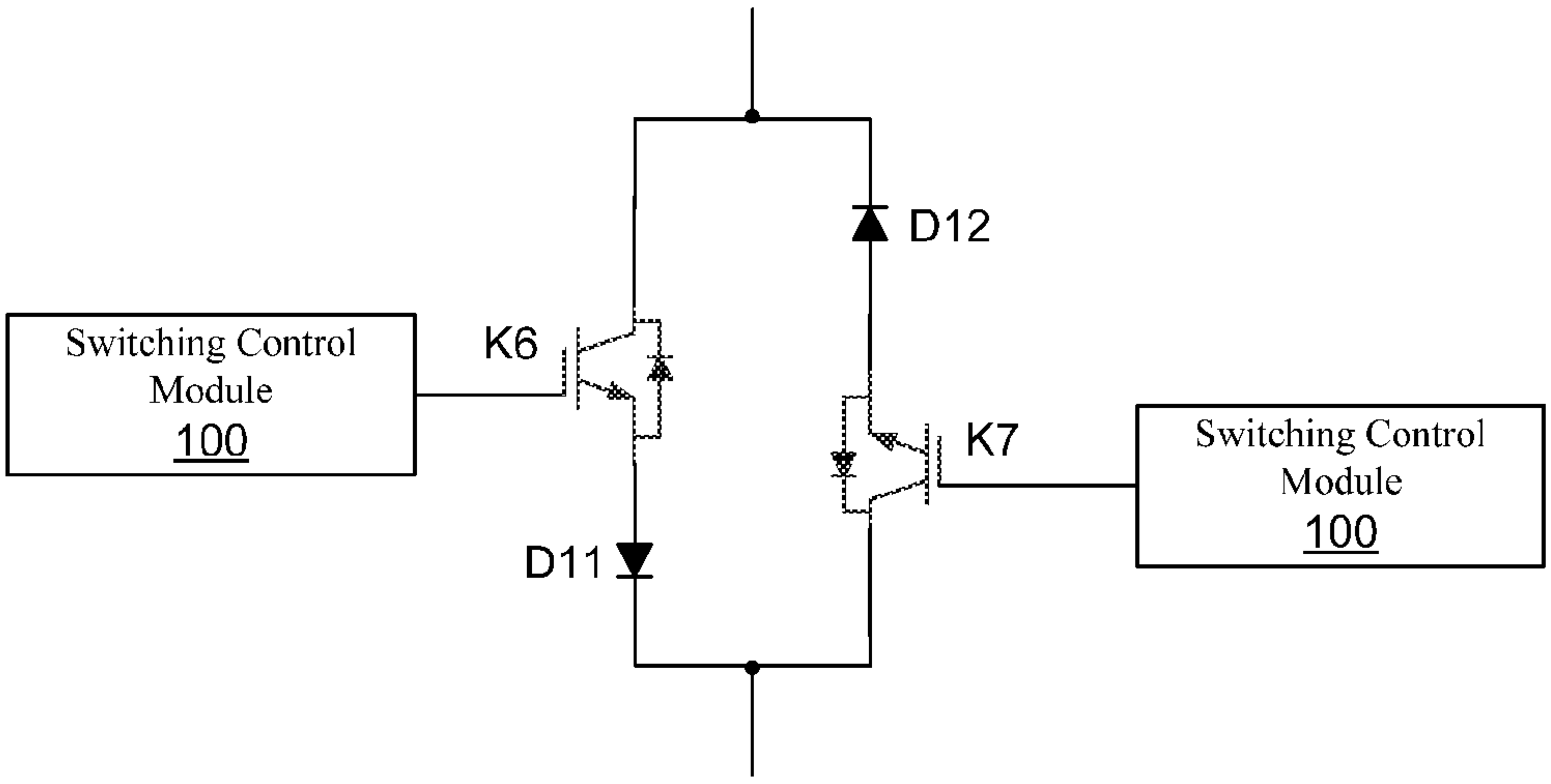


Figure 12

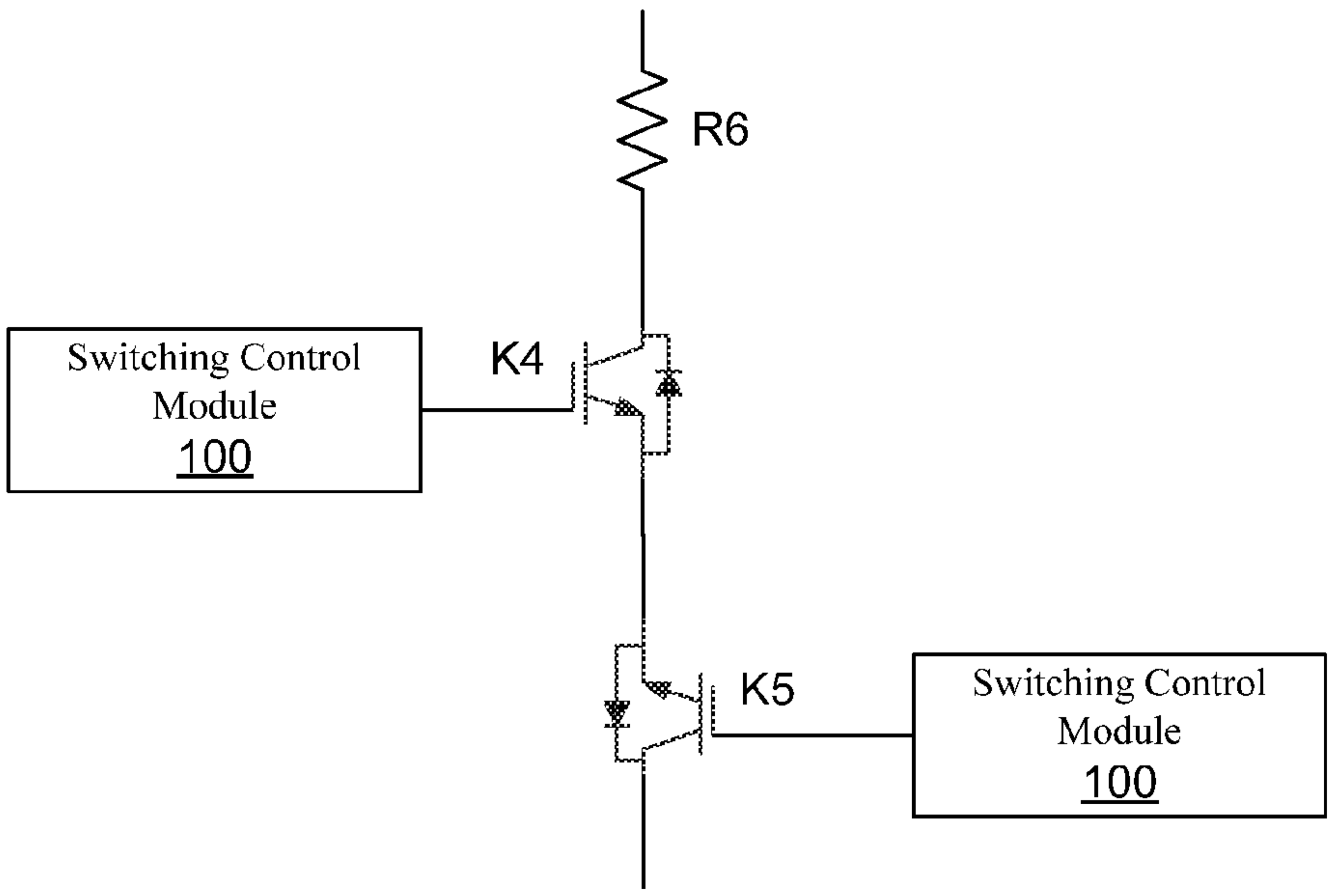


Figure 13

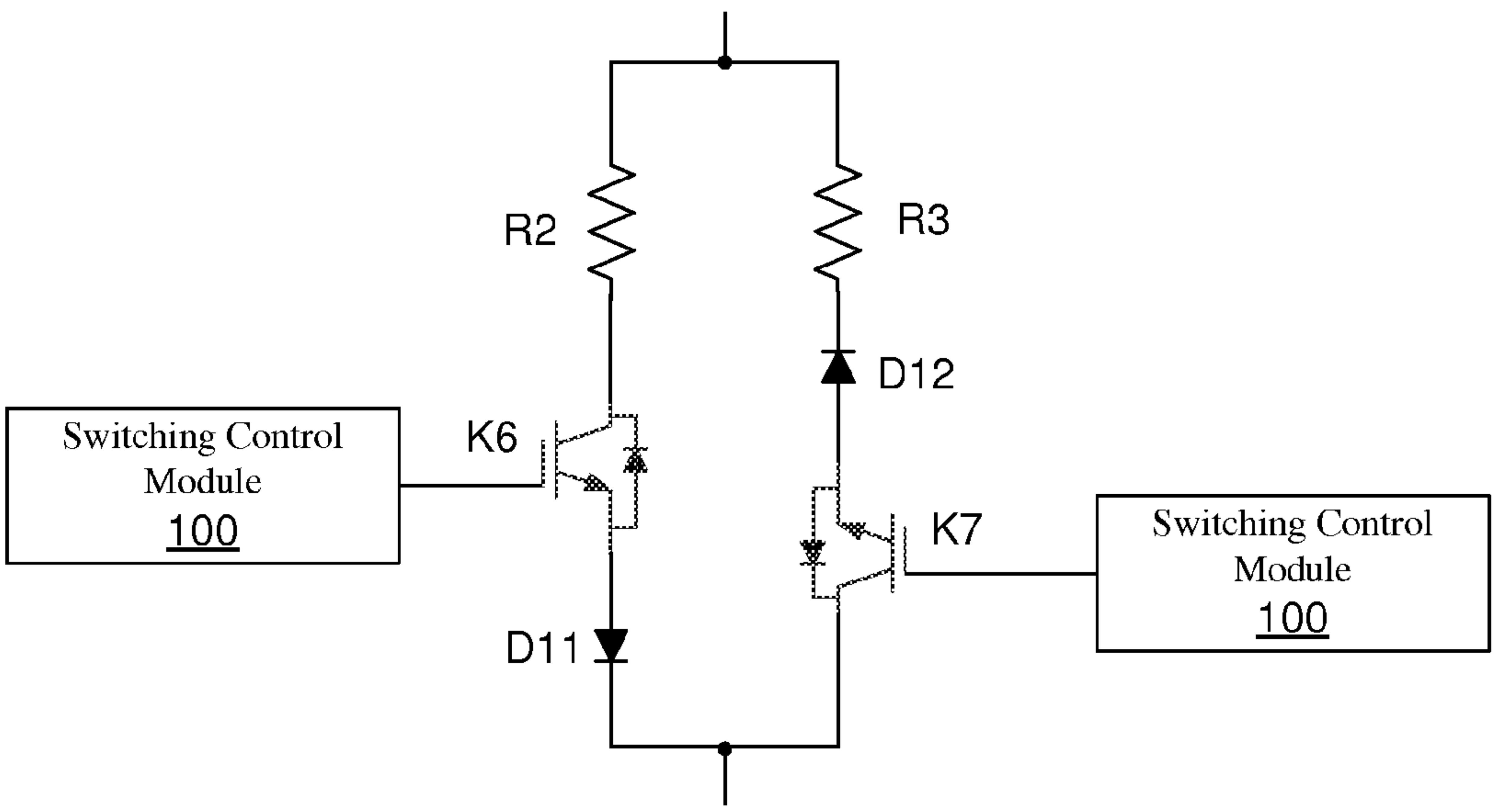


Figure 14

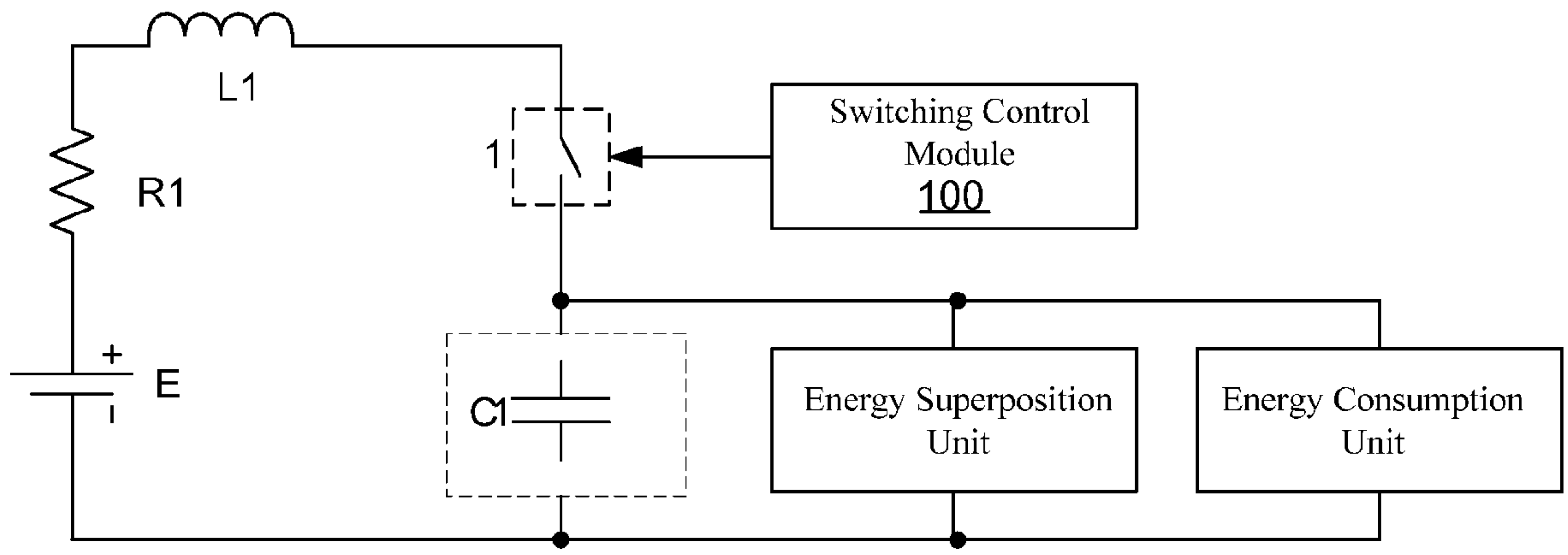


Figure 15

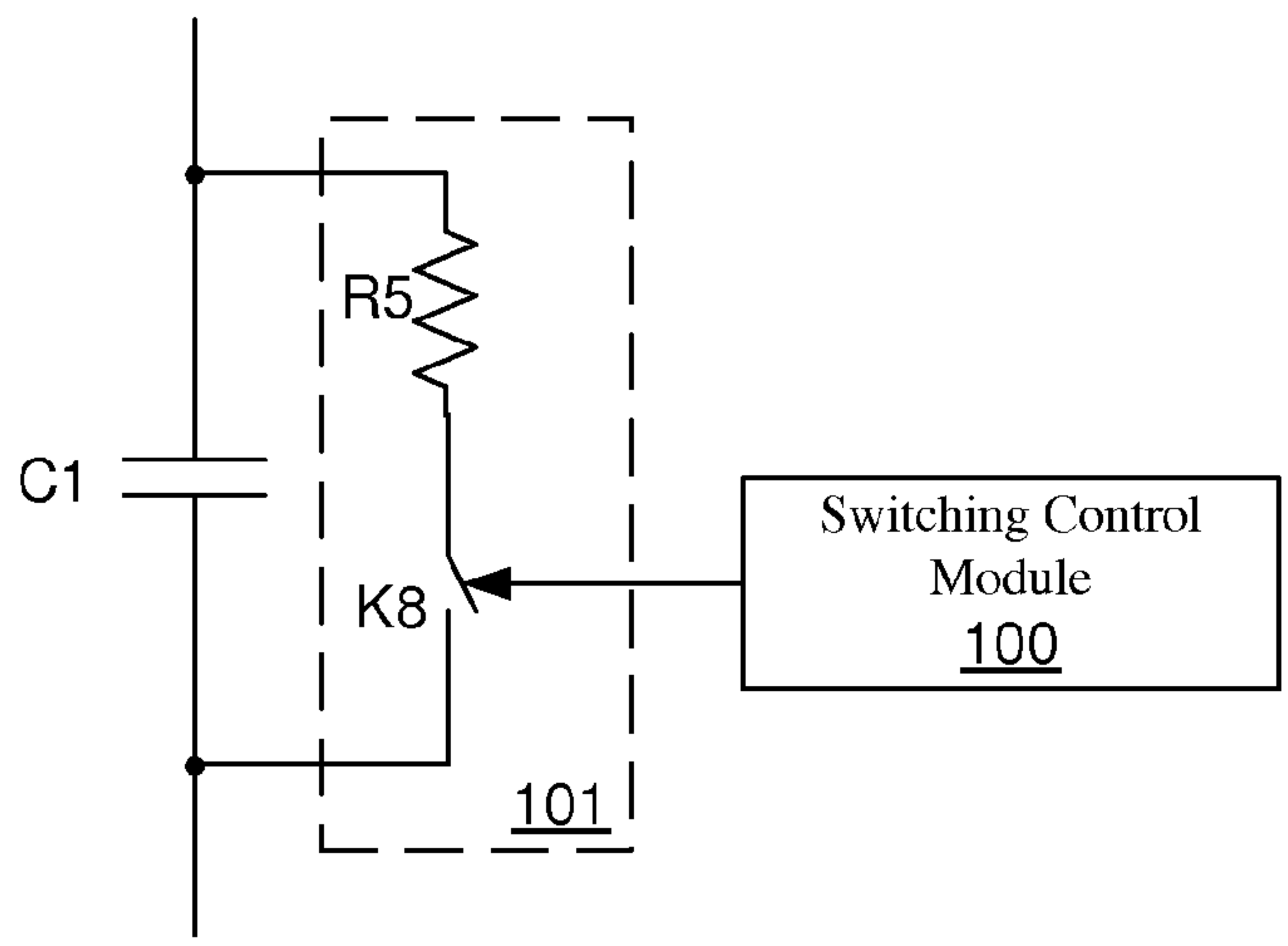


Figure 16

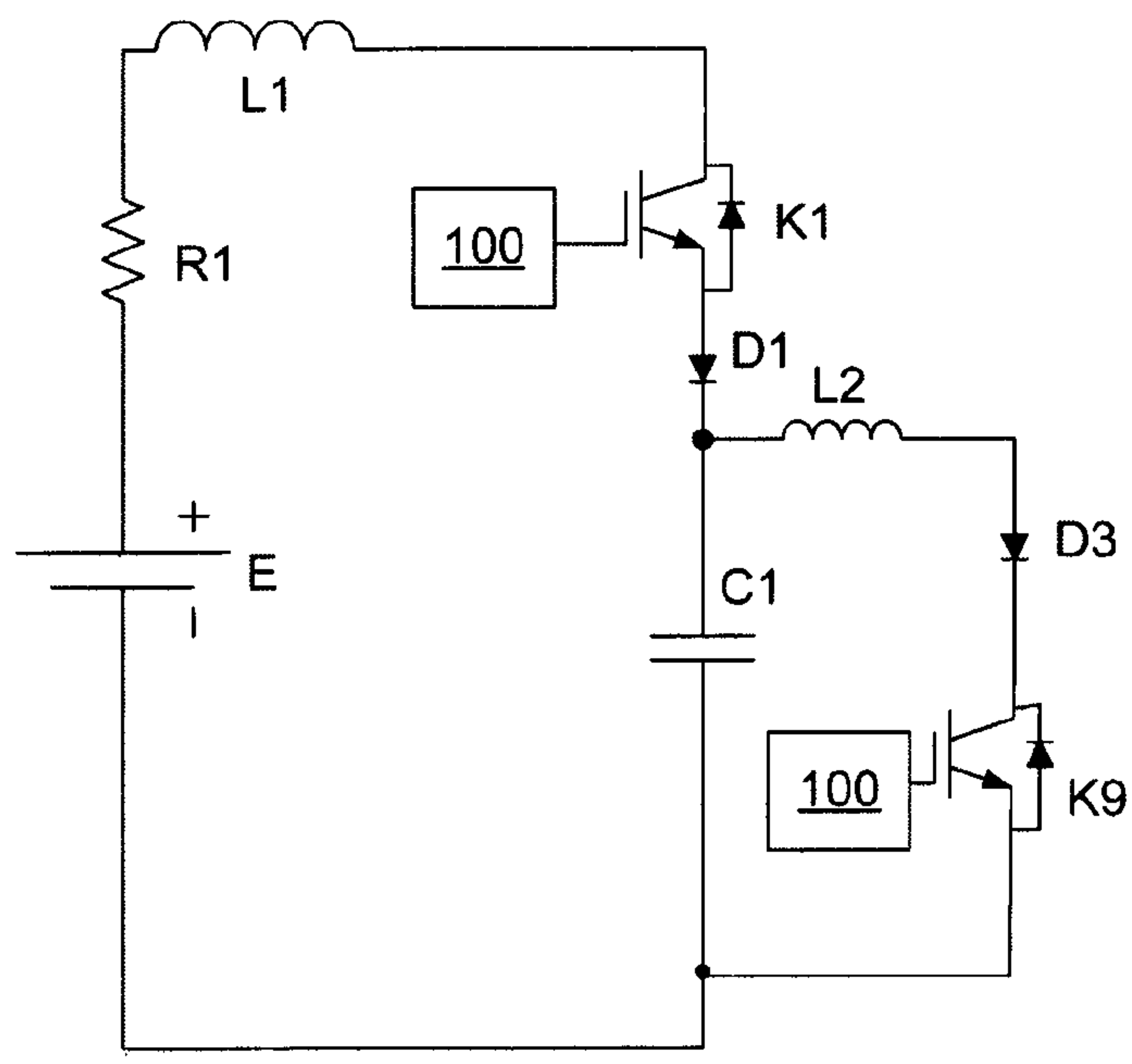


Figure 17

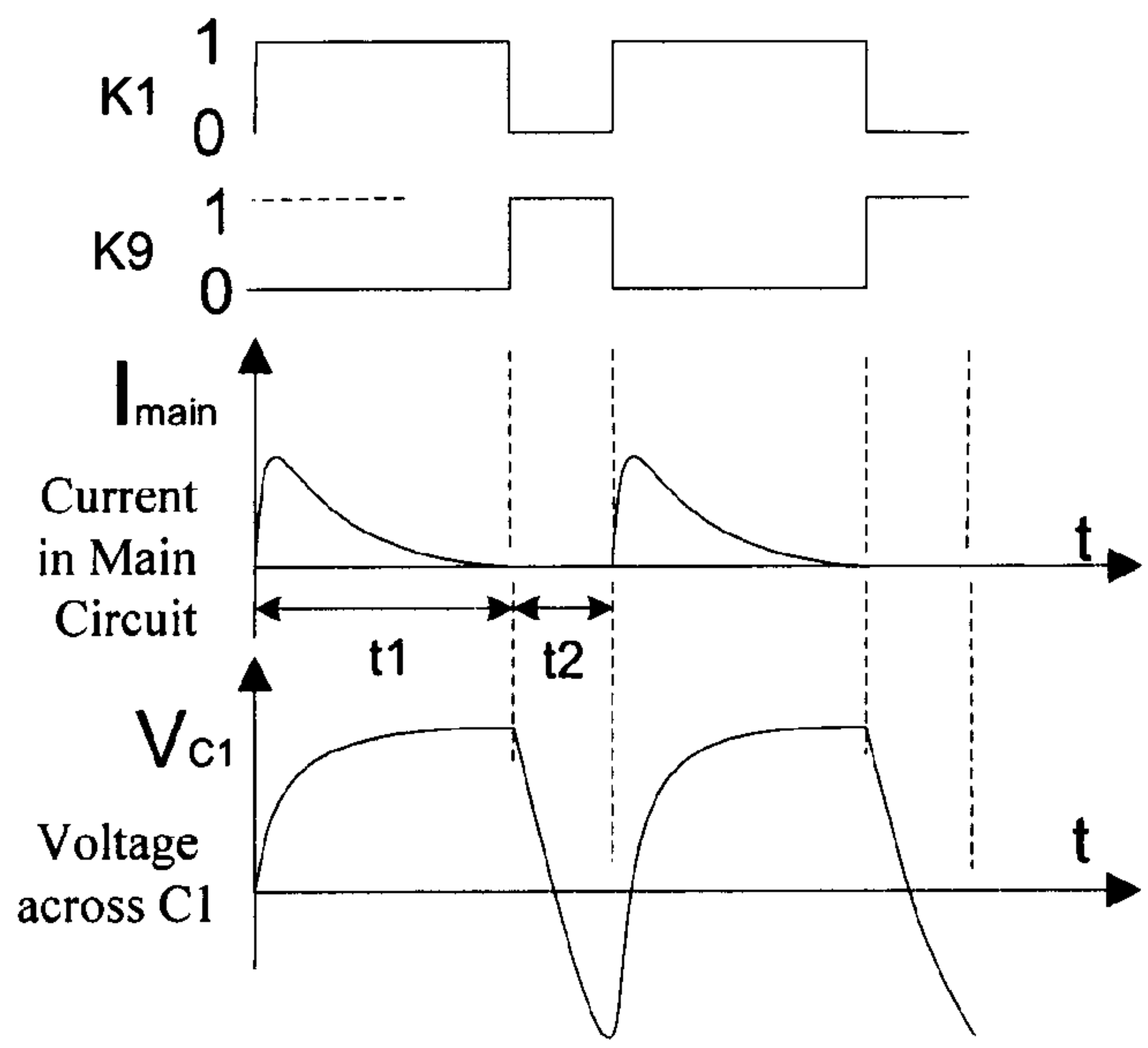


Figure 18

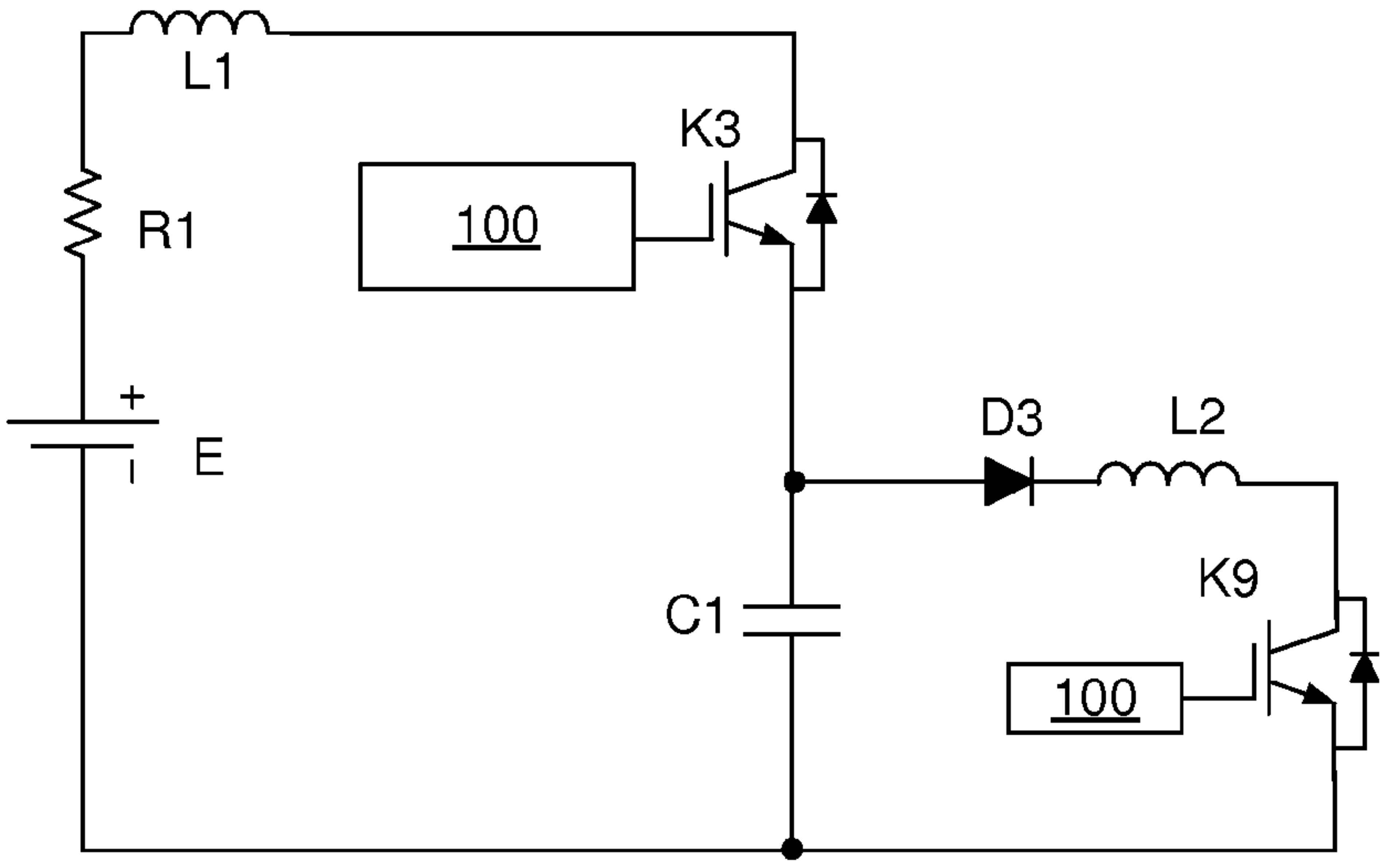


Figure 19

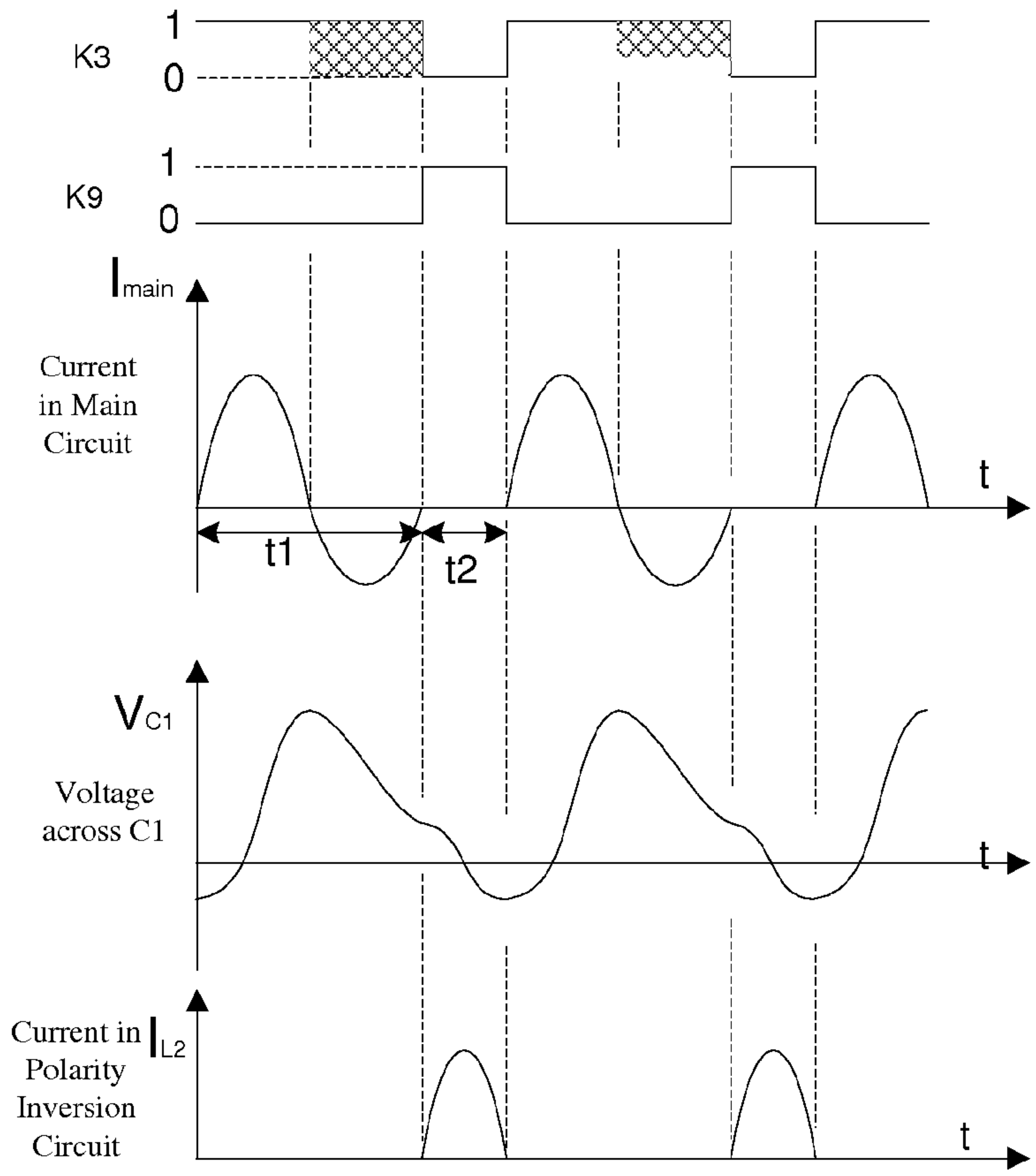
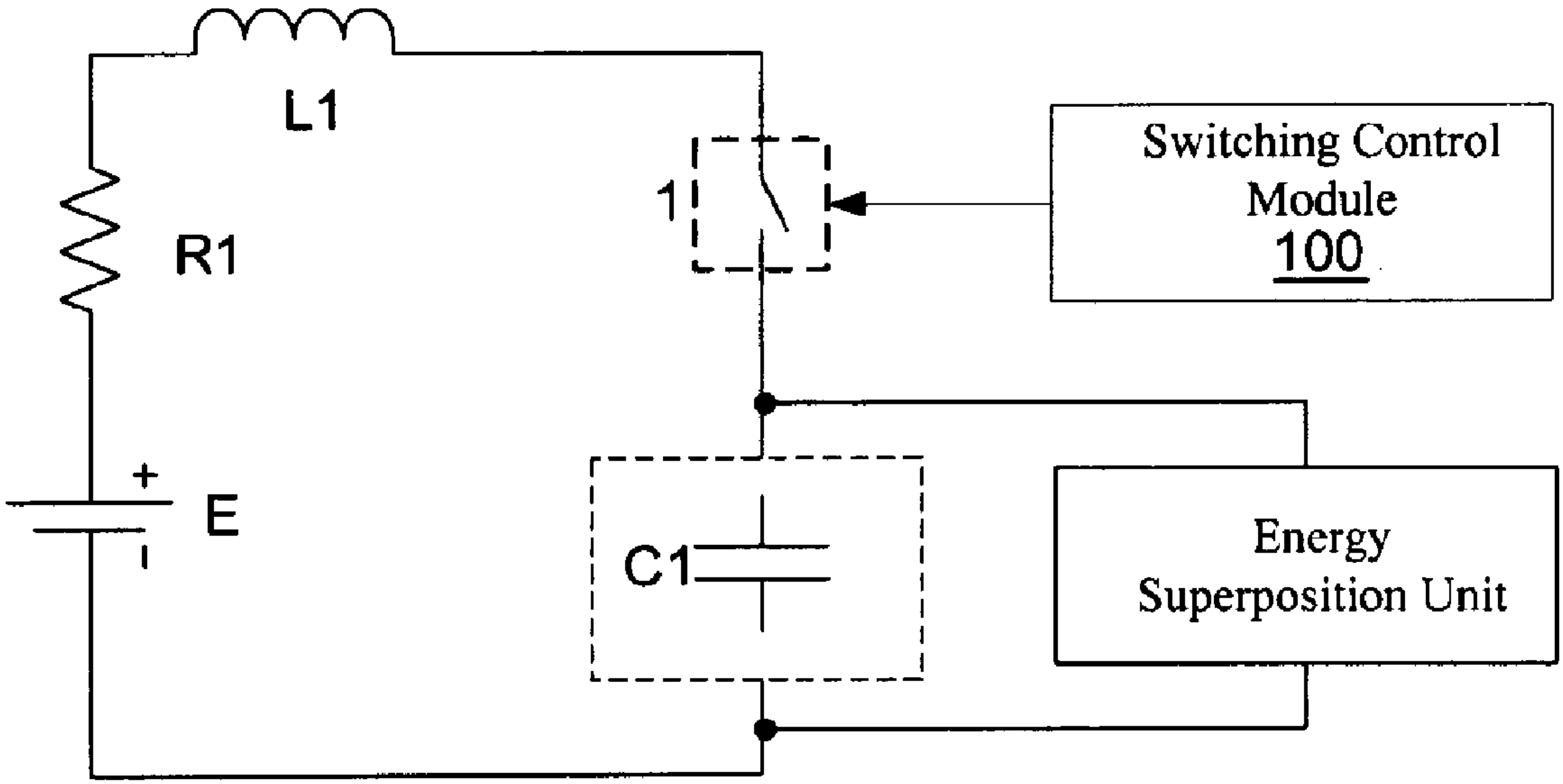


Figure 20


L1
R1
E
+
1
C1
Switching Control
Module
100
Energy
Superposition Unit