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(54) **HIGH EFFICIENCY POWER REGULATOR AND METHOD**

(58) **Field of Classification Search**

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See application file for complete search history.

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(57) **ABSTRACT**

A power regulator comprises a first power switch configured to carry a pulsed current, an input capacitor between a positive terminal of an input voltage bus and a return point, an output capacitor between a positive terminal of an output voltage bus and the return point and a protection device coupled between the return point and a common return point of the input voltage bus and the output voltage bus, wherein the pulsed current is configured to flow through the protection device.

**19 Claims, 8 Drawing Sheets**

(65) **Prior Publication Data**

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**Related U.S. Application Data**

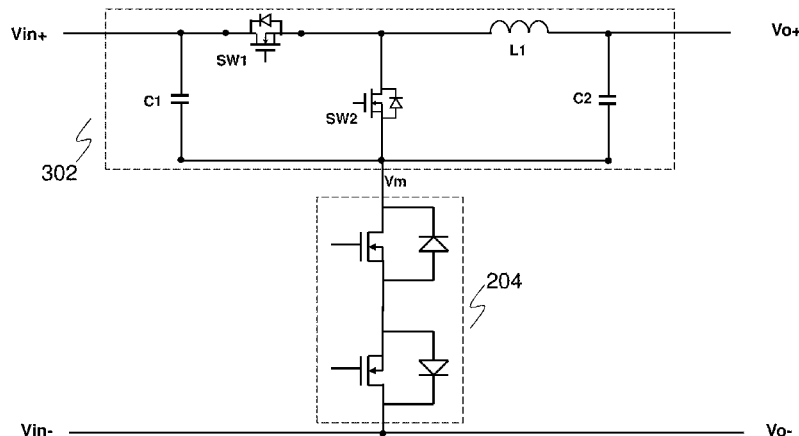
(63) Continuation of application No. 14/252,912, filed on Apr. 15, 2014, now Pat. No. 9,337,641, which is a continuation of application No. 13/198,178, filed on Aug. 4, 2011, now Pat. No. 8,717,717.

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**H01R 43/26** (2006.01)  
**H02H 3/00** (2006.01)  
**H02H 9/02** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H02M 3/158** (2013.01); **H01R 43/26** (2013.01); **H02H 3/003** (2013.01); **H02H 9/02** (2013.01); **H02H 9/025** (2013.01); **H02M 1/32** (2013.01); **H02M 3/1582** (2013.01); **Y10T 29/49117** (2015.01)



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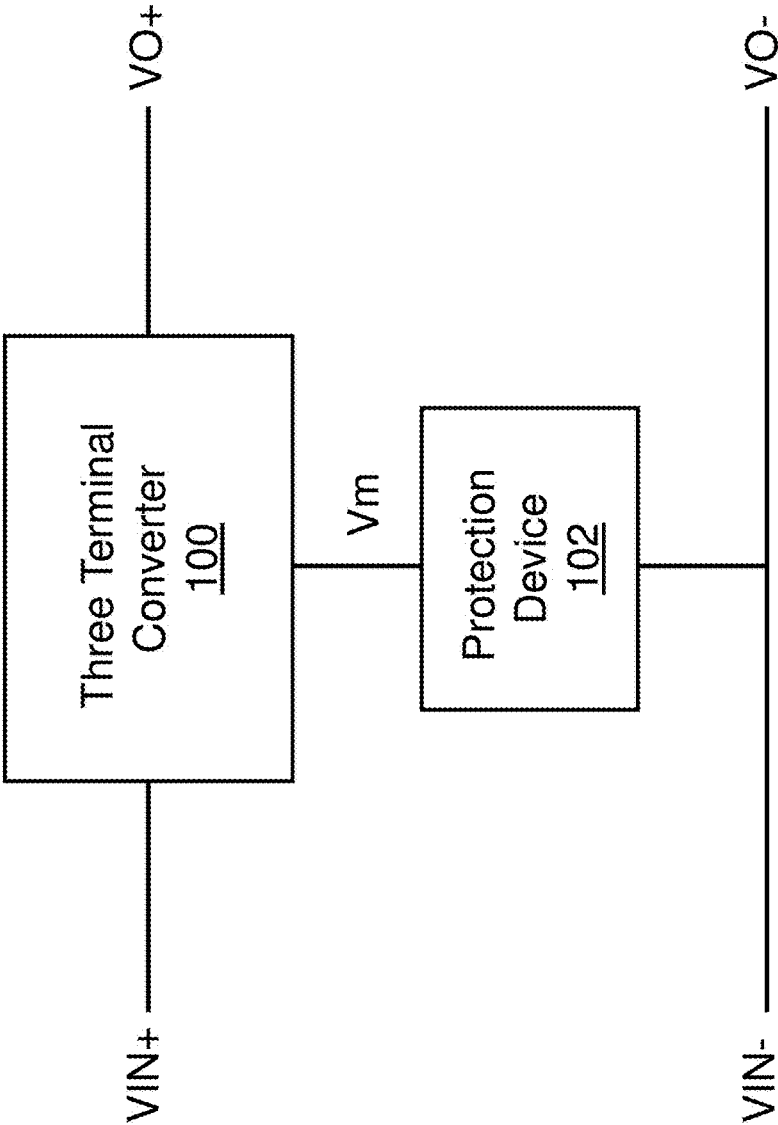


Figure 1

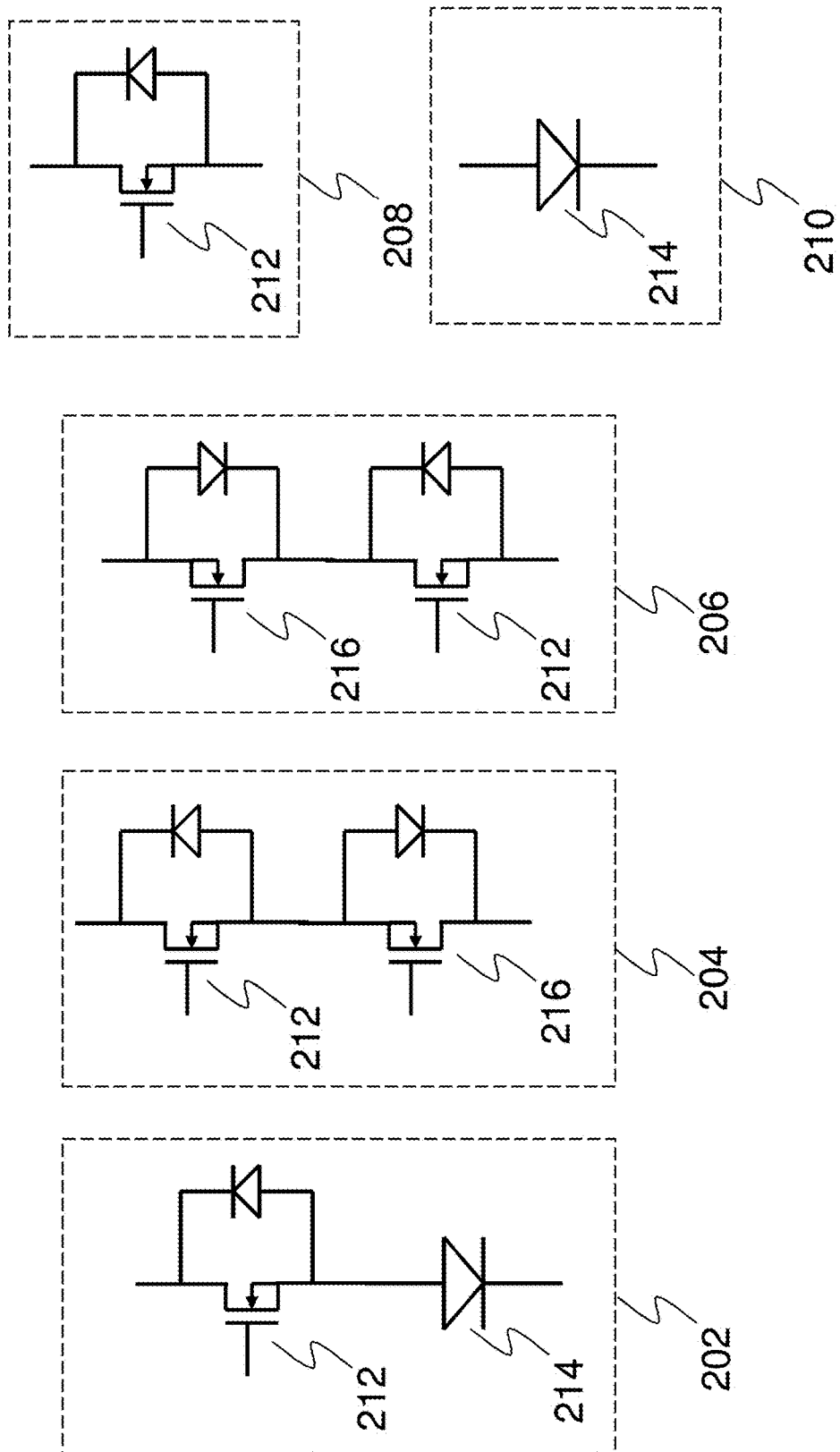


Figure 2

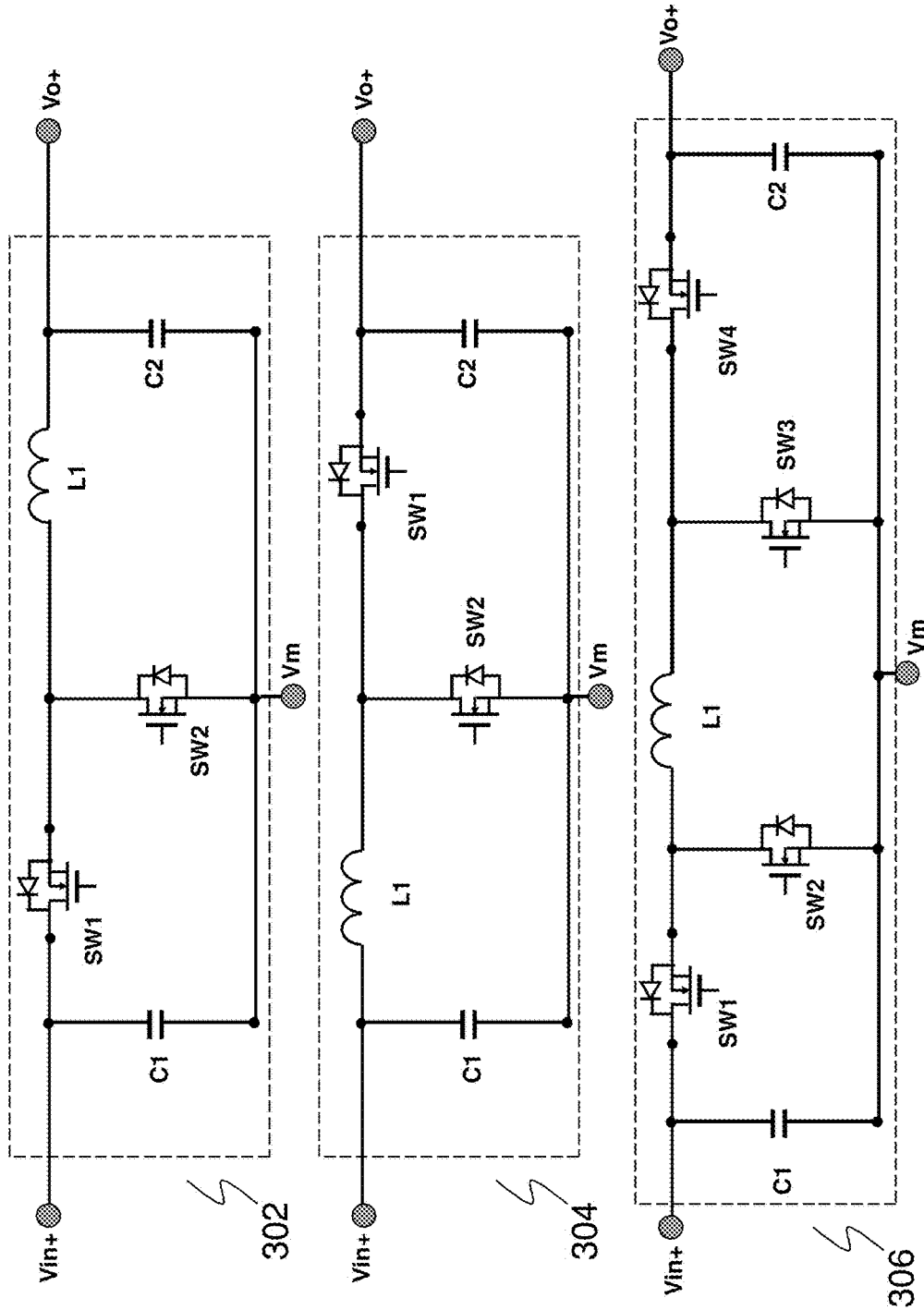


Figure 3

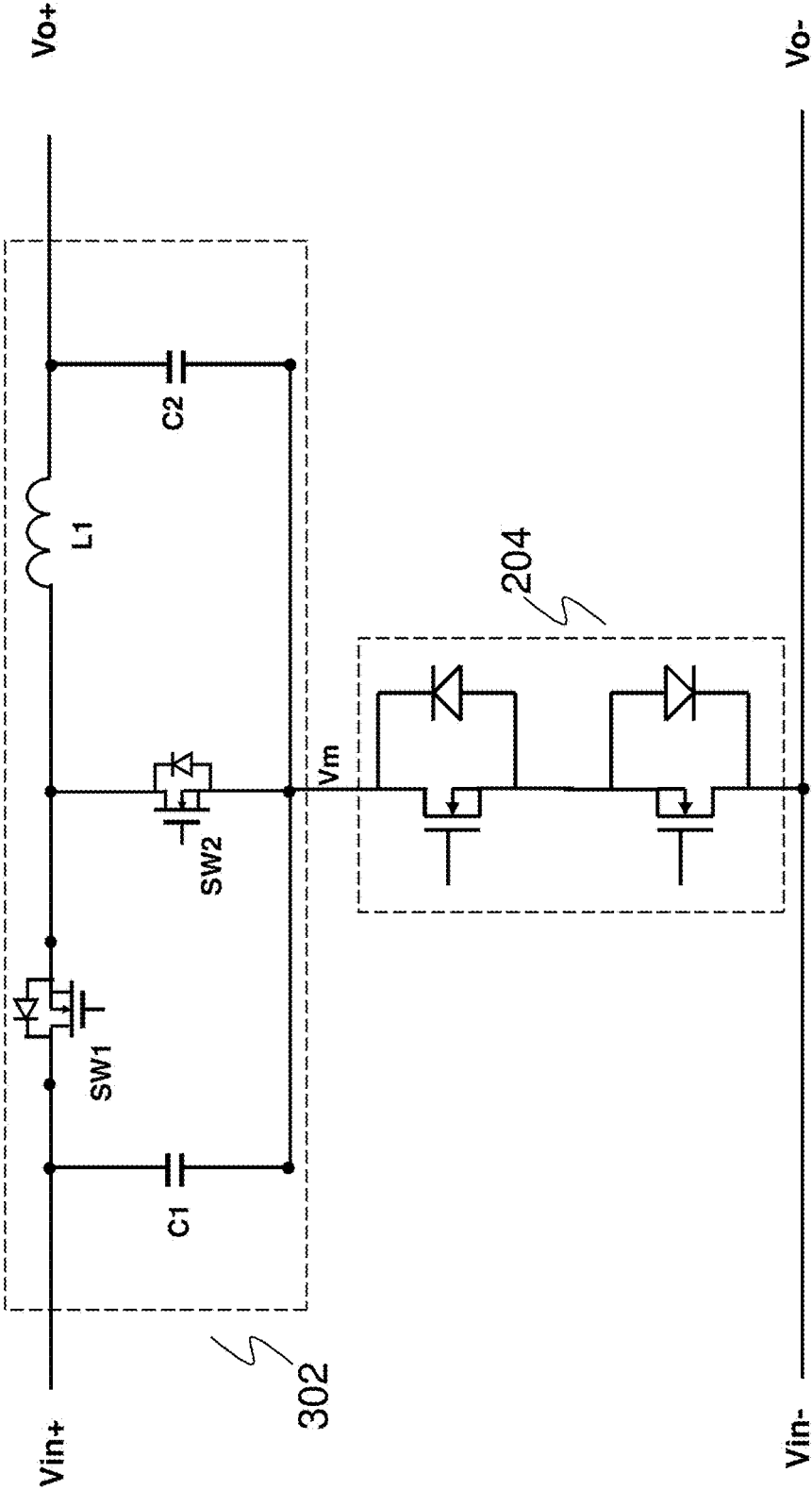


Figure 4

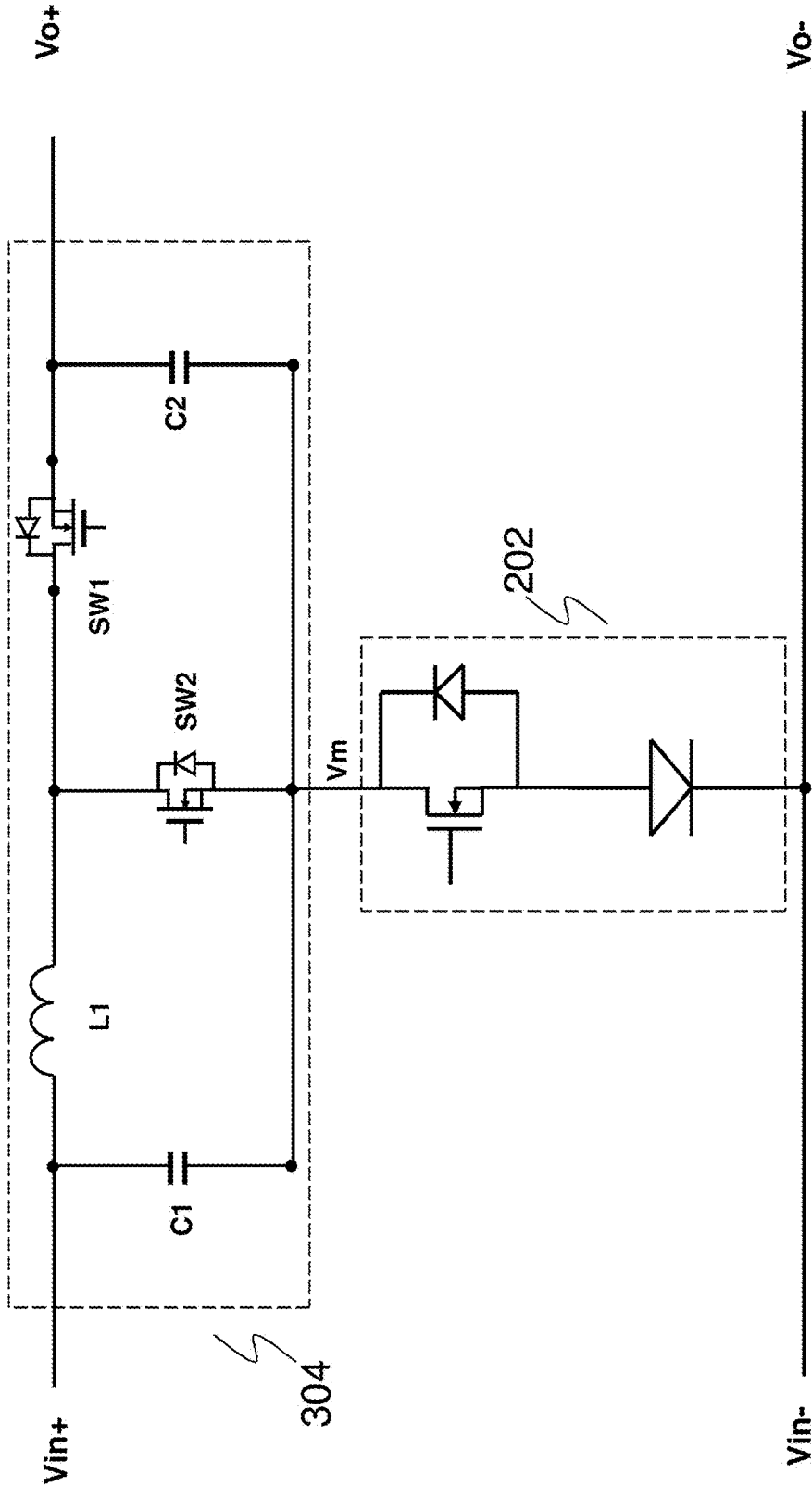


Figure 5

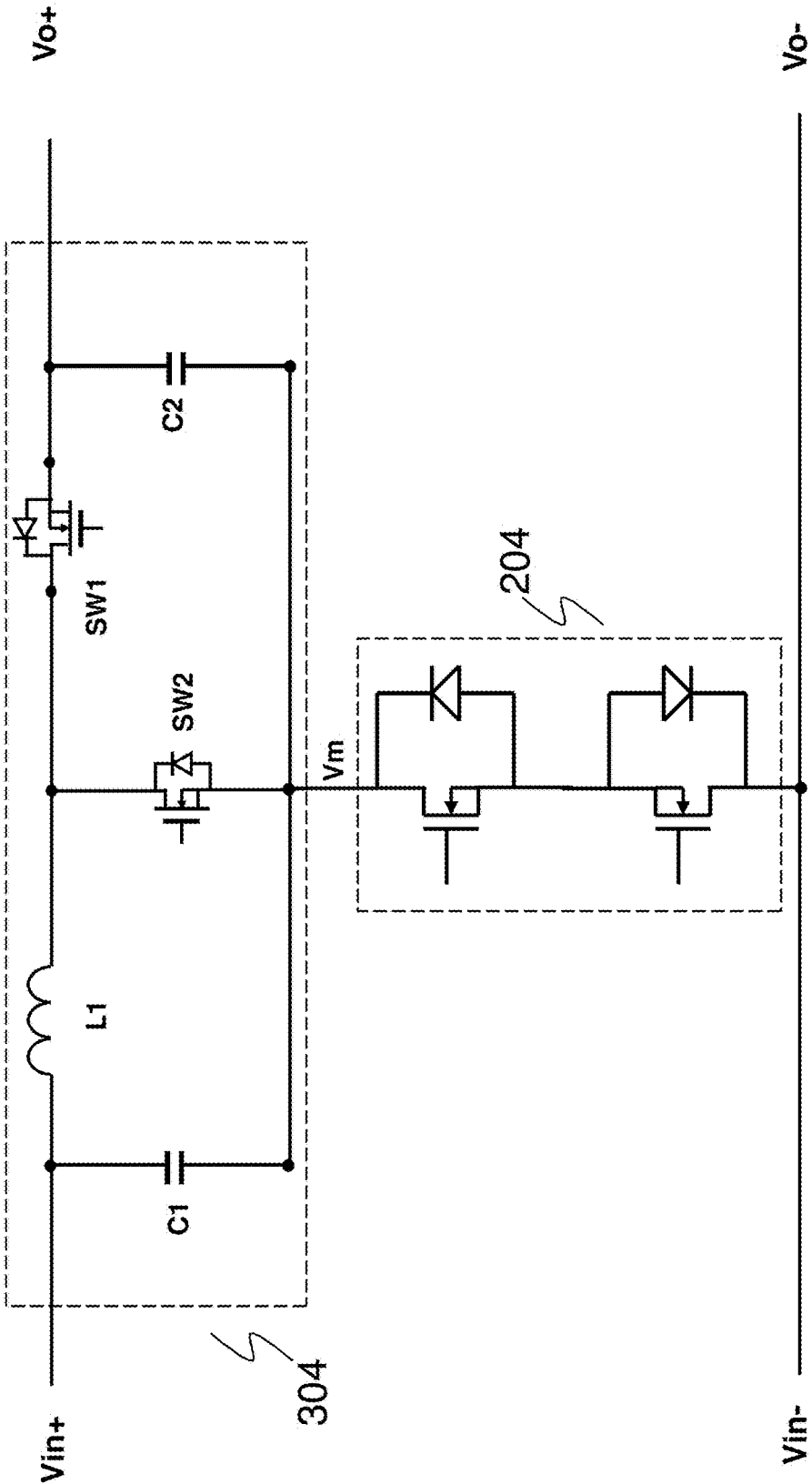


Figure 6



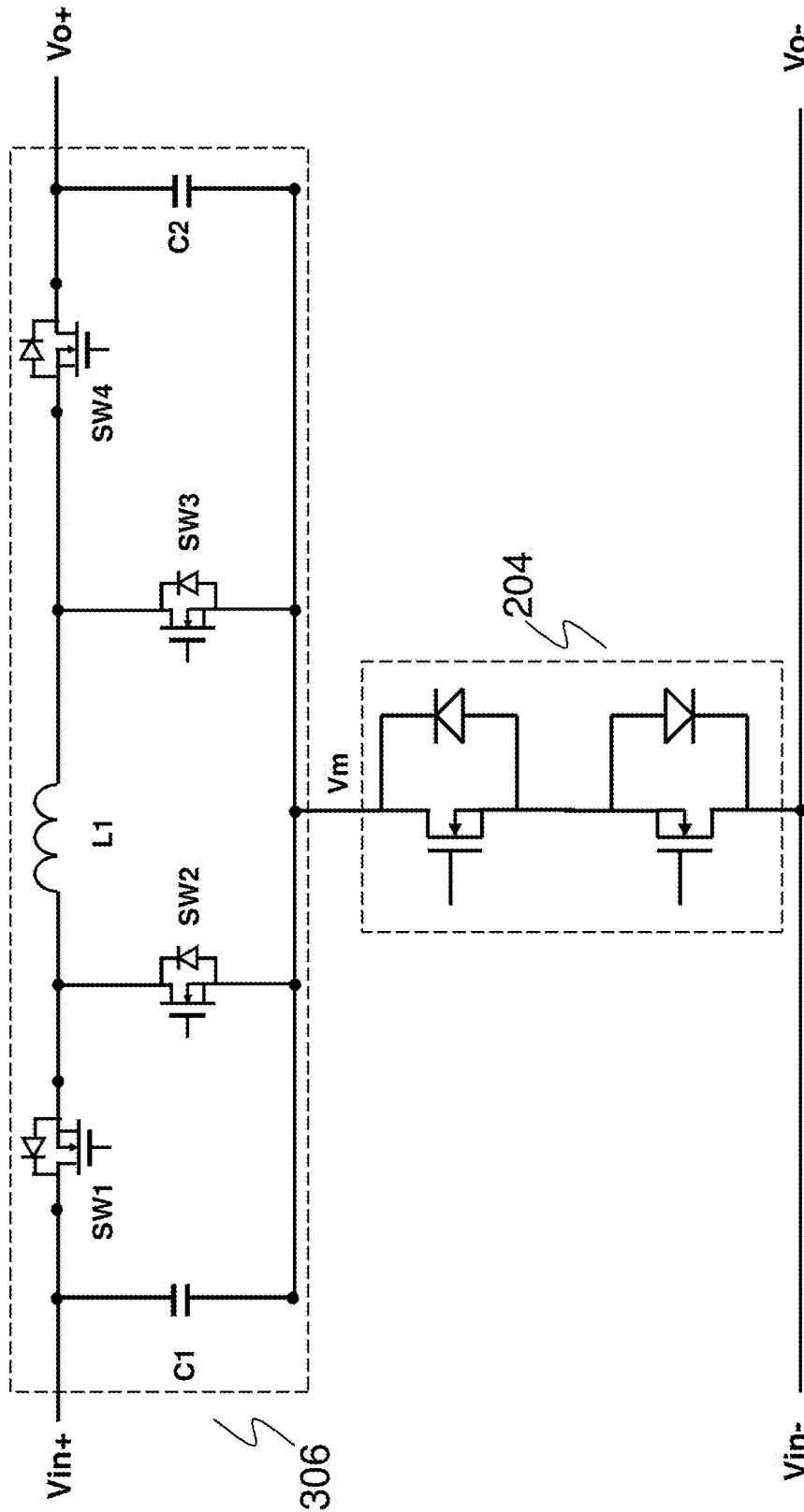


Figure 7

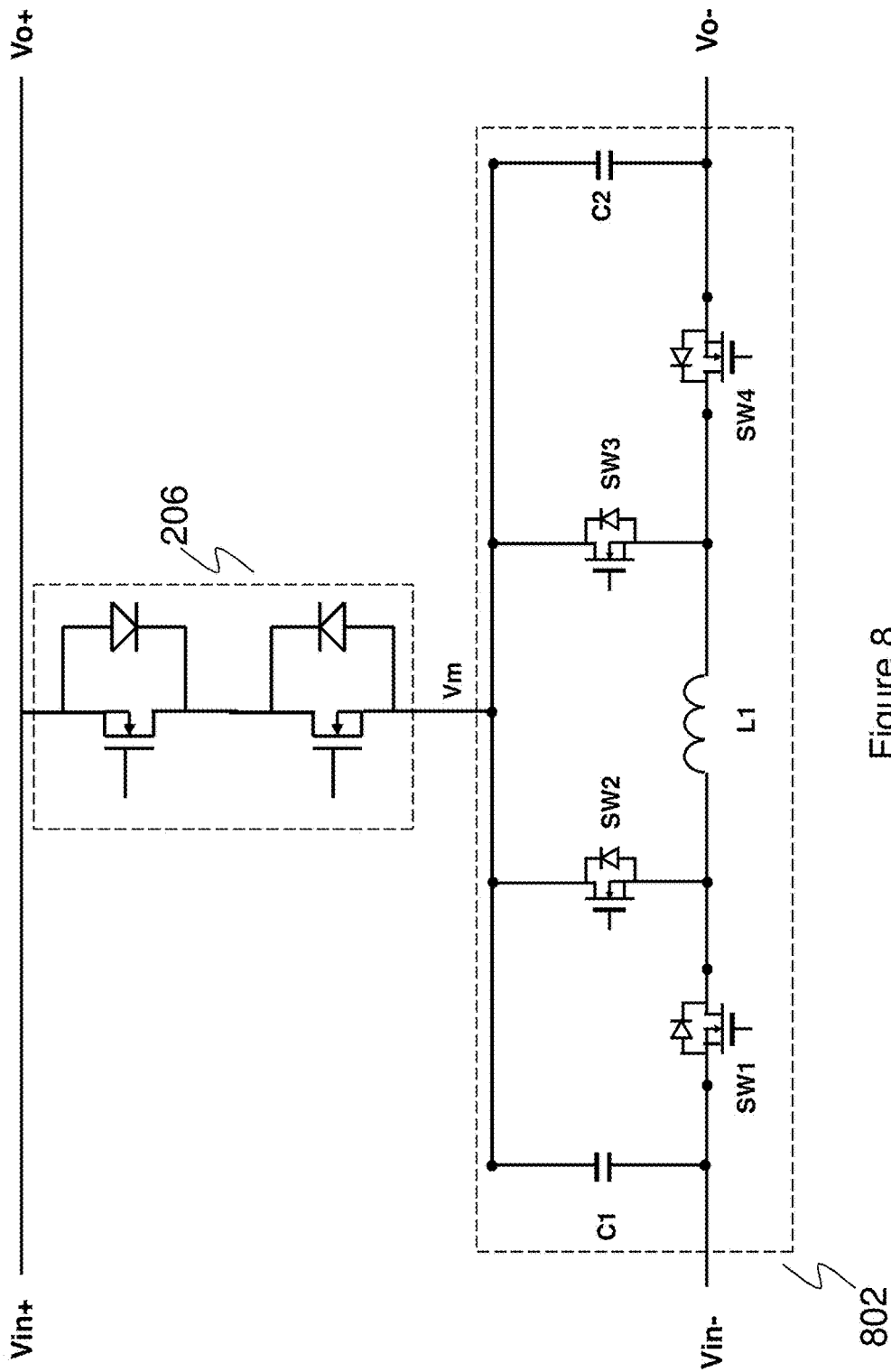


Figure 8

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## HIGH EFFICIENCY POWER REGULATOR AND METHOD

This application is a continuation application of U.S. patent Ser. No. 14/252,912, entitled "High Efficiency Power Regulator and Method," filed on Apr. 15, 2014 which is a continuation of U.S. patent application Ser. No. 13/198,178, entitled "High Efficiency Power Regulator and Method," filed on Aug. 4, 2011, which applications are incorporated herein by reference.

### TECHNICAL FIELD

The present invention relates to devices and methods for non-isolated dc-dc power regulators, and more particularly, to devices and methods for non-isolated dc-dc regulators comprising a protection or control device.

### BACKGROUND

A telecommunication network power system usually includes an ac-dc stage converting the power from the ac utility line to a 48V dc distribution bus and a dc-dc stage converting the 48V dc distribution bus to a plurality of voltage levels for all types of telecommunication loads. Alternatively, the 48V dc distribution bus may be converted into a low voltage bus through an isolated dc-dc converter. Furthermore, a plurality of downstream non-isolated dc-dc converters with inputs coupled to the low voltage bus may generate a variety of voltage levels in accordance with the needs of the telecommunication network power system. Usually, the dc distribution bus may have a relatively wide voltage rang. For example, the dc distribution bus may have a range from 36V to 75V in a normal operation mode. During a transient, the dc distribution bus' transient voltage is usually up to 100V.

To achieve an optimized distributed power system, one or more non-isolated power converters may be used to reduce the range variation of the distribution bus voltage. The non-isolated dc-dc converters can be implemented by using different power topologies, such as buck dc-dc converters, boost dc-dc converters, buck-boost dc-dc converters, linear regulators and/or the like.

In order to have a reliable telecommunication power system, a variety of protection devices may be connected in series with non-isolated dc-dc converters to form non-isolated dc-dc regulators. For example, an inrush current limiting device such as an n-type metal oxide semiconductor (NMOS) transistor may be placed between an input voltage bus and a buck dc-dc converter. When the buck dc-dc converter is plugged into the input voltage bus, the inrush current limiting device helps to reduce the current flowing into the dc-dc converter by slowly turning on the NMOS transistor. Likewise, a reverse polarity protection device may be connected in series with a dc-dc converter. The reverse polarity protection device helps to prevent a current flowing into the dc-dc converter when reverse polarity occurs. Conventionally, these protection switches are placed in the main power path of the dc-dc converter. As a result, the protection switches may endure full voltage and current stresses of the dc-dc converter. Such full voltage and current stresses may cause extra power losses in the dc-dc converter.

### SUMMARY OF THE INVENTION

These and other problems are generally solved or circumvented, and technical advantages are generally achieved, by

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preferred embodiments of the present invention which provide a system, structure and method for achieving a high efficiency non-isolated dc-dc switching regulator.

In accordance with an embodiment, a system comprises a three-terminal converter having a first terminal connected to a first input voltage bus, a second terminal connected to a first output voltage bus and a third terminal connected to a first terminal of a protection device and the protection device having a second terminal connected to a common node of a second input voltage bus and a second output voltage bus.

In accordance with another embodiment, a regulator comprises a first power switch configured to carry a pulsed current, an input capacitor between a positive terminal of an input voltage bus and a return point, an output capacitor between a positive terminal of an output voltage bus and the return point and a protection device coupled between the return point and a common return point of the input voltage bus and the output voltage bus, wherein the pulsed current is configured to flow through the protection device.

In accordance with yet another embodiment, a method comprises operating a power regulator in a high duty cycle mode, wherein the power regulator comprises a three-terminal converter having a first terminal connected to a first input voltage bus, a second terminal connected to a first output voltage bus and a third terminal connected to a first terminal of a protection device and the protection device having a second terminal connected to a common node of a second input voltage bus and a second output voltage bus and configuring the power regulator such that a current flowing through the protection device is equal to a current flowing through a power switch of the three-terminal converter.

An advantage of an embodiment of the present invention is reducing the size and power loss of a dc-dc regulator so as to improve the efficiency, reliability and cost of a power system.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures or processes for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates a block diagram of a high efficiency power regulator in accordance with an embodiment;

FIG. 2 illustrates five embodiments of the protection device **102** shown in FIG. 1;

FIG. 3 illustrates three embodiments of the three-terminal converter **100** shown in FIG. 1;

FIG. 4 illustrates a schematic diagram of a three-terminal buck dc-dc converter and a protection device in accordance with an embodiment;

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FIG. 5 illustrates a schematic diagram of a three-terminal boost dc-dc converter and a protection device in accordance with another embodiment;

FIG. 6 illustrates a schematic diagram of a three-terminal boost dc-dc converter and a protection device in accordance with yet another embodiment;

FIG. 7 illustrates a schematic diagram of a three-terminal buck-boost dc-dc converter and a protection device in accordance with yet another embodiment; and

FIG. 8 illustrates a schematic diagram of a three-terminal buck-boost dc-dc converter and a protection device in accordance with yet another embodiment.

Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the various embodiments and are not necessarily drawn to scale.

#### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the presently preferred embodiments are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

The present invention will be described with respect to preferred embodiments in a specific context, namely a high efficiency buck dc-dc converter. The invention may also be applied, however, to a variety of dc-dc converters including buck dc-dc converters, boost dc-dc converters, buck-boost dc-dc converters, flyback converters, forward converters, half bridge and full bridge converters and the like.

Referring initially to FIG. 1, a block diagram of a high efficiency power regulator is illustrated in accordance with an embodiment. The high efficiency power regulator comprises a three-terminal converter 100 and a protection device 102. The three-terminal converter 100 may be part of non-isolated regulators including buck dc-dc converters, boost dc-dc converters, buck-boost dc-dc converters and the like. The protection device 102 may comprise a variety of power supply protection functions such as inrush current limiting, reverse polarity protection and the like. The three-terminal converter 100 has a first terminal coupled to a positive terminal of an input voltage bus, a second terminal coupled to a positive terminal of an output voltage bus and a third terminal coupled to an intermediate point  $V_m$  as well as a terminal of the protection device 102. As shown in FIG. 1, the other terminal of the protection device 102 is coupled to both a negative terminal of the input voltage bus and a negative terminal of the output voltage bus. In accordance with an embodiment, both the negative terminal of the input voltage bus and the negative terminal of the output voltage bus may be further coupled to ground. One advantageous feature of having the protection device 102 coupled between the intermediate point  $V_m$  and ground is that the current stress as well as the power losses at the protection device 102 may be reduced so that the efficiency of the power converter shown in FIG. 1 can be improved.

FIG. 2 illustrates five embodiments of the protection device 102 shown in FIG. 1. A first protection device 202 comprises a first n-type metal oxide semiconductor (NMOS) transistor 212 and a diode 214 connected in series. As shown in FIG. 2, the source of the first NMOS transistor 212 is connected to the anode of the diode 214. The NMOS

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transistor 212 and the diode 214 connected in series form a protection device for a three-terminal regulator (illustrated in FIG. 1). More particularly, the diode 214 may provide reverse polarity protection and the first NMOS transistor 212 may be used as an inrush current limiting device.

The NMOS transistor 212 functions as a slow start switch controlled by a controller (not shown). When an input voltage is suddenly applied to a power regulator, the NMOS transistor 212 connected between the input voltage and the power converter may be turned on slowly. As a result, the current flowing through the NMOS transistor 212 ramps up slowly so that the input voltage of the power converter increases slowly to its normal voltage. It should be noted that while FIG. 2 shows the protection device 202 employs an NMOS transistor 212 as a current limiting element, one of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, the protection device 202 may employ other and alternate embodiment current limiting elements, such as negative temperature coefficient (NTC) thermistors, fixed resistors and the like.

The protection device 202 further comprises a reverse polarity protection element. As known in the art, a diode may allow an electric current to pass in forward direction, while preventing the electric current from flowing in the opposite direction. As such, when a power converter is plugged into an input voltage bus with reverse polarity, the protection device 202 comprising the diode 214 may prevent an electric current from flowing into the power converter so as to keep the reverse voltage applied to the input of the power converter from damaging the internal circuits of the power converter.

Alternatively, the diode 214 of the protection device 202 can be replaced by a second NMOS transistor 216 shown in the protection device 204. The second NMOS transistor 216 can be used as a series diode by turning off the second NMOS transistor 216. On the other hand, when the series diode operates in a forward conduction mode, the turned on NMOS transistor 216 may reduce the voltage drop across the protection device 204. An advantageous feature of replacing a series diode with an NMOS transistor is that the turned on voltage drop across an NMOS transistor is much less than that of a series diode. As a result, the efficiency of the power protection device can be further improved. It should be noted while FIG. 2 shows using an NMOS transistor 216 to replace the series diode 214, one skilled in the art will recognize that the NMOS transistor 216 illustrated in FIG. 2 is simply one embodiment and that other devices can be employed. For example, the series diode 214 can be replaced by a p-type metal oxide semiconductor (PMOS) transistor.

The protection device 206 shown in FIG. 2 is an alternative embodiment of the protection device 204. The protection device 206 can be formed by swapping the first NMOS transistor 212 and the second NMOS transistor 216 of the protection device 204. It should be noted that there may be various embodiments for achieving the same functions provided by the protection device 206. For example, both the first NMOS transistor 212 and the second NMOS transistor 216 can be replaced by PMOS transistors. In addition, either the first NMOS transistor 212 or the second NMOS transistor 216 can be replaced by a plurality of transistors connected in series or in parallel.

FIG. 2 further illustrates a fourth protection device 208 and a fifth protection device 210. As shown in FIG. 2, the fourth protection device 208 comprises the first NMOS transistor 212. Likewise, the fifth protection device 210 comprises the diode 214. It should be noted that in accor-

dance with an embodiment, a protection device (e.g., protection device 202) may comprise an NMOS transistor and a diode connected in series. However, a protection device having two component connected in series is merely an example, which should not unduly limit the scope of the claims. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, a power regulator may employ a protection device comprising a diode (e.g., protection device 210) or an NMOS transistor (e.g., protection device 208). The number of components in a protection device is limited solely for the purpose of clearly illustrating the inventive aspects of the various embodiments. The present invention is not limited to any specific number of components in a protection device.

FIG. 3 illustrates three embodiments of the three-terminal converter 100 shown in FIG. 1. The first three-terminal converter 302 is a buck dc-dc converter comprising a first NMOS transistor SW1, a second NMOS transistor SW2, an input capacitor C1, an output capacitor C2 and an output inductor L1. The operation principles of a buck dc-dc converter are well known in the art, and hence are not discussed in further detail herein. The second three-terminal converter 304 is a boost dc-dc converter comprising a first NMOS transistor SW1, a second NMOS transistor SW2, an input capacitor C1, an output capacitor C2 and an output inductor L1. The boost dc-dc converter 304 is used to provide an output voltage higher than an input voltage by modulating the width of a pulse applied to the first NMOS transistor SW1. The operation principles of the boost dc-dc converter are well known in the art, and hence are not discussed in further detail herein.

The third three-terminal converter 306 is a buck-boost dc-dc converter comprising a buck dc-dc converter plus a boost dc-dc converter. More particularly, when the buck-boost dc-dc converter 306 operates in a step-up mode, the first NMOS transistor SW1 is turned on and the second NMOS transistor SW2 is turned off. As a result, the inductor L1, the third NMOS transistor SW3 and the fourth NMOS transistor SW4 form a boost dc-dc converter having the same system configuration as that of the boost dc-dc converter 304. On the other hand, when the buck-boost dc-dc converter operates in a step-down mode, the fourth NMOS transistor SW4 is turned on and the third NMOS transistor SW3 is turned off. As a result, the first NMOS transistor SW1 and the second NMOS transistor SW2 and the inductor L1 form a buck dc-dc converter having the same system configuration as that of the buck dc-dc converter 302.

FIG. 4 illustrates a schematic diagram of a three-terminal buck dc-dc converter and a protection device in accordance with an embodiment. As known in the art, in accordance with the operation principles of buck dc-dc converters, the high side switch and the low side switch operate in a complementary mode. The ratio of the conduction time of the high side switch over the switching period of a buck dc-dc converter is referred to as the duty cycle of the buck dc-dc converter. The duty cycle is set by a PWM controller or the like. To maintain the output voltage at a predetermined voltage, when the output voltage drops below the predetermined voltage, the high side switch is turned on and the low side switch is turned off so that the output capacitor is charged from the input through the turned on high side switch and the output inductor. On the other hand, when the output voltage exceeds the predetermined voltage, the PWM controller turns off the high switch and turns on the low side switch so that the output voltage is discharged to ground through the turned on low side switch and the output inductor. As a result, the electronic circuits coupled to the

buck dc-dc converter can receive a constant output voltage under load and temperature fluctuations.

In steady state operation of a buck converter, the input dc current flowing into the Vin+ terminal is equal to the product of the current flowing out of the Vo+ terminal and the duty cycle of the first NMOS transistor SW1. As shown in FIG. 4, the current flowing through the protection device 204 (from bottom to top) in steady state operation is the difference between the output current flowing out of the Vo+ terminal and the input current flowing into the Vin+ terminal. When the output voltage is close to the input voltage of the buck dc-dc converter 302, the duty cycle of the first NMOS transistor SW1 is relatively high as a result. Therefore, the output current flowing out of the Vo+ terminal is not much different from the input current flowing into the Vin+ terminal. As such, the current flowing through the protection device 204 is much lower than the input current flowing into the Vin+ terminal. As a result, the current stress as well as the power loss of the protection device 204 is reduced. In sum, an advantageous feature of having a protection device 202 as shown in FIG. 4 is that the efficiency of a power regulator can be improved by reducing the power loss at the protection device 204.

FIG. 5 illustrates a schematic diagram of a three-terminal boost dc-dc converter and a protection device in accordance with another embodiment. Similar to that of FIG. 4, when the boost dc-dc converter 304 operates in a high duty cycle mode, the protection device 202 may experience a lower current value in comparison with the power architecture having a protection device connected in series with the boost dc-dc converter 304. As a result, the power loss of the protection device 202 may be reduced.

FIG. 6 illustrates a schematic diagram of a three-terminal boost dc-dc converter and a protection device in accordance with yet another embodiment. The system configuration of FIG. 6 is similar to that of FIG. 5 except that the protection device 202 is replaced by the protection device 204. One skilled in the art will recognize that the protection device 202 can also be replaced by the protection device 206 shown in FIG. 2. Any combinations between protection devices shown in FIG. 2 and the three-terminal regulators shown in FIG. 3 are within the scope of the present invention.

FIG. 7 illustrates a schematic diagram of a three-terminal buck-boost dc-dc converter and a protection device in accordance with yet another embodiment. When the buck-boost dc-dc converter 306 operates in a buck dc-dc converter mode with a high duty cycle, the protection device 204 may experience a low RMS current value in comparison with the power architecture having a protection device connected in series with the buck-boost dc-dc converter 306. Likewise, when the buck-boost dc-dc converter 306 operates in a boost dc-dc converter mode with a high duty, the protection device 204 may experience a lower current value in comparison with the power architecture having a protection device connected in series with the buck-boost dc-dc converter 306. As a result, the total efficiency of the buck-boost dc-dc converter 306 may be improved.

FIG. 8 illustrates a schematic diagram of a three-terminal buck-boost dc-dc converter and a protection device in accordance with yet another embodiment. The system configuration of the buck-boost dc-dc converter 802 is similar to that of the buck-boost dc-dc converter 306 shown in FIG. 7 except that the buck-boost dc-dc converter 802 is connected with a negative power system. More particularly, the common return of both the input and the output has a higher voltage than either the input or the output. The operation principles of a negative power system are well known in the

art, and hence are not discussed in detail to avoid repetition. An advantageous feature of having the protection device 206 connected between the common return and the intermediate point Vm is that the power loss of the protection device may be reduced when the buck-boost dc-dc converter operates in a high duty cycle mode.

Although embodiments of the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A system comprising:
  - a three-terminal converter having a first terminal connected to a first input voltage bus, a second terminal connected to a first output voltage bus and a third terminal connected to a first terminal of a protection device comprising a switching element; and
  - the protection device having a second terminal connected to a common node of a second input voltage bus and a second output voltage bus, wherein: a portion of an output current flowing through the second output voltage bus is configured to flow through the protection device.
2. The system of claim 1, wherein: the portion of the output current is equal to a current flowing through a power switch of the three-terminal converter.
3. The system of claim 1, wherein the protection device comprises:
  - an inrush current limiting element; and
  - a reverse polarity protection element.
4. The system of claim 3, wherein: the inrush current limiting element is connected in series with the reverse polarity protection element.
5. The system of claim 1, wherein: the three-terminal converter is a buck dc-dc converter.
6. The system of claim 1, wherein: the three-terminal converter is a boost dc-dc converter.
7. The system of claim 1, wherein: the three-terminal converter is a buck-boost dc-dc converter.
8. The system of claim 1, wherein: the first input voltage bus is a positive input voltage bus; and the first output voltage bus is a positive output voltage bus.
9. The system of claim 1, wherein: the second input voltage bus is a negative input voltage bus; and

the second output voltage bus is a negative output voltage bus, and wherein the second input voltage bus is directly connected to the second output voltage bus.

10. A regulator comprising:
  - a first power switch configured to carry a pulsed current; an input capacitor between a positive terminal of an input voltage bus and a return point;
  - an output capacitor between a positive terminal of an output voltage bus and the return point; and
  - a protection device coupled between the return point and a common return point of the input voltage bus and the output voltage bus, wherein the pulsed current is configured to flow through the protection device.
11. The regulator of claim 10, further comprising: a second power switch and an inductor, wherein the first power switch, the second power switch and the inductor form a buck dc/dc converter.
12. The regulator of claim 10, further comprising: a second power switch and an inductor, wherein the first power switch, the second power switch and the inductor form a boost dc/dc converter.
13. The regulator of claim 10, further comprising: a second power switch, a third power switch, a fourth power switch and an inductor, wherein the first power switch, the second power switch, the third power switch, the fourth power switch and the inductor form a buck-boost dc/dc converter.
14. The regulator of claim 10, wherein: the protection device comprises an inrush current limiting element and a reverse polarity protection element, and wherein the inrush current limiting element is connected in series with the reverse polarity protection element.
15. A method comprising:
  - operating a power regulator in a high duty cycle mode, wherein the power regulator comprises:
    - a three-terminal converter having a first terminal connected to a first input voltage bus, a second terminal connected to a first output voltage bus and a third terminal connected to a first terminal of a protection device; and
    - the protection device having a second terminal connected to a common node of a second input voltage bus and a second output voltage bus; and
  - configuring the power regulator such that a current flowing through the protection device is equal to a current flowing through a power switch of the three-terminal converter.
16. The method of claim 15, wherein: the protection device comprises an inrush current limiting device and a reverse polarity protection device.
17. The method of claim 15, further comprising: configuring the power regulator such that a pulsed current flowing through the protection device is equal to a pulsed current flowing through a power switch of the three-terminal converter.
18. The method of claim 15, wherein: the three-terminal converter is a buck dc/dc converter comprising a high side switch and a low side switch.
19. The method of claim 17, further comprising: configuring the three-terminal converter such that a current flowing through the low side switch is equal to a current flowing through the protection device.

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