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(54) High precision DC to DC converter with wide load range and gate drive circuit for use therein

Hochpräziser Gleichstrom-Gleichstrom-Wandler für einen weiten Leistungsbereich, und Treiberschaltung für diesen Wandler

Convertisseur CC-CC de haute précision à large plage de charge, et circuit de commande de grille pour utilisation dans celui-ci

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- **FIGGE H ET AL: "Paralleling of LLC resonant converters using frequency controlled current balancing", POWER ELECTRONICS SPECIALISTS CONFERENCE, 2008. PESC 2008. IEEE, IEEE, PISCATAWAY, NJ, USA, 15 June 2008 (2008-06-15), pages 1080-1085, XP031300116, ISBN: 978-1-4244-1667-7**

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Description

BACKGROUND

(a) Technical Field

[0001] The present invention relates to a resonant converter. More particularly, the present invention relates to a resonant converter that enables high efficient precision control even at no load or light load in which low power is used.

(b) Background Art

[0002] Generally, DC/DC converters have been widely used in various industrial fields to convert an input DC voltage into an output DC voltage at a different level. The DC/DC converter converts a DC voltage into an AC voltage, and then the AC voltage is either raised or dropped by a transformer to be rectified again into a DC voltage, allowing the voltage to be transformed.

[0003] There are many circuit configurations for implementing the DC/DC converter, and one example thereof is a resonant converter. The resonant converter uses a resonant phenomenon of an inductor Lr and a capacitor Cr.

[0004] FIG. 11 is a view illustrating control characteristics of a resonant converter according to the switching frequency, which shows the resonant converter operating in a continuous conduction region has to increase the switching frequency to lower the output voltage. As an example, the switching frequency needs to further increase to lower a current from an output of 4 A to an output of 2 A.

[0005] However, when the switching frequency becomes higher, a switching loss of the resonant converter increases.

[0006] FIG. 12 is a view illustrating a loss of an Insulated Gate Bipolar Transistor (IGBT) when the output power (voltage and current) is lowered for the use at a light load region.

[0007] That is, in the DC/DC resonant converter operation in the continuous conduction region, the IGBT loss rapidly increases during the light load operation, and thus, the efficiency can be rapidly reduced or the switching element such as the IGBT can be damaged by burning.

[0008] The above information disclosed in this Background section is only for enhancement of understanding of the background of the invention and therefore it may contain information that does not form the prior art that is already known in this country to a person of ordinary skill in the art.

[0009] US 2011/254528 A discloses a multi-module bidirectional power converter comprising a low side common node, a high side common node and at least first and second bidirectional DC/DC converter modules comprising first and second low voltage switches, first and second high voltage switches and a transformer. Such converter provides operability with any one or more of the modules so that efficiency is maintained when electrical loads are high and so that Zero Voltage Switching is maintained when electrical loads are low.

[0010] DE 43 37 504 A1 discloses a method and a device for turning on an electric field controlled gate turn-off power semiconductor of a resonant converter operating in zero voltage switch mode. Before an on control signal arrives a check is made whether the valve voltage of the power semiconductor is approximately zero, whereby in the case the valve voltage is not approximately zero it is switched from a turn-on switch operation with high switching speed to a turn-on operation at a matched switching speed. Thereby the operation of the resonant converter can be maintained even in the case of a load change or malfunction of the inductor without applying an overvoltage to the power semiconductors of the converter.

[0011] According to "Paralleling of LLC resonant converters using frequency controlled current balancing", POWER ELECTRONICS SPECIALISTS CONFERENCE, 2008. PESC 2008. IEEE, IEEE, PISCATAWAY, NJ, USA, 15 June 2008, pages 1080-1085, ISBN: 978-1-4244-1667-7, paralleling of two LLC resonant converters leads to a significant reduction of current stress in the output filter capacitor, provided that the driving signals of both converters are of equal frequency and with constant phase shift of 90deg. However, non influenceable tolerances of the circuit elements, especially those of the resonant tank circuit, cause unbalanced power distribution between the paralleled converters, resulting in suboptimal circuit design. To overcome this, phase shifted paralleling of two LLC resonant converters and frequency controlled current balancing is used.

SUMMARY OF THE DISCLOSURE

[0012] The present invention provides a DC/DC converter that can be used in all load ranges(from no load to full load) from the no load condition to the rated load condition including the light load condition while maintaining the low conduction loss_and switching loss of the resonant converter.

[0013] The present invention also provides a high precision DC/DC converter that can minimize a ripple component of an output voltage in a process of producing a desired output voltage through the DC power conversion.

[0014] The present invention also provides a high precision DC/DC converter that can protect a sensitive load from an arc to minimize the energy transmitted to the load because it is possible to control with high accuracy and to reduce ripples without increasing the value of filter capacitor.

[0015] The present invention provides a DC/DC converter, to which a switching frequency can be stably applied even in a power on/off process.

[0016] In one aspect, the present invention provides an isolated resonant converter for converting a direct current (DC) into another direct current (DC) with a desired level, where when a light load is connected, only a single switch leg is operated to take charge of the light load,

the resonant converter including: a first switch leg having one end connected to a positive terminal of a DC power source_and the other end connected to a negative terminal of the DC power source,

the first switch leg being operated as a single-phase half-bridge inverter at a first switching frequency under a light load condition and being operated together with one or more second switch legs at a second switching frequency being lower than the first switching frequency under a rated load condition or a high load condition; the one or more second switch legs having one end connected to the positive terminal of the DC power source and the other end connected to the negative terminal of the DC power source and being operated at the second switching frequency under a rated load condition.

[0017] Further, the first and second switch legs each includes two switching units connected in series, and each switching unit may include: a power semiconductor switching element; a diode including a cathode connected to a current inflow terminal of the power semiconductor switching element and an anode connected to a current outflow terminal of the power semiconductor switching element; a snubber capacitor connected in parallel to the diode; and a gate drive circuit applying a switching signal to a terminal for turning-on/off control of the power semiconductor switching element,

and wherein a value of snubber capacitor for preventing a rapid voltage increase of the first switch leg is designed to be smaller than a value of the snubber capacitor of the one or more second switch legs such that zero voltage sensing of the gate drive circuit of the first switch leg is faster than zero voltage sensing of the gate drive circuit of the second switch leg.

[0018] In still another exemplary embodiment, the gate drive circuit may be configured to include a first power semiconductor switching element, a second power semiconductor switching element, first to third diodes, and first to eighth resistors, and a capacitor. In order to distinguish a charge path and a discharge path of a current applied to the terminal for the turning-on/off control of the power semiconductor switching element of the switching unit, a gate drive signal may be inputted into the current outflow terminal of the first power semiconductor switching element, and one end of the sixth resistor may be connected to the current outflow terminal of the first power semiconductor switching element. The current outflow terminal of the first power semiconductor switching element may be connected to one end of the capacitor, one end of the fourth resistor, one end of the second resistor, and the current outflow terminal of the power semiconductor switch element of the switching unit. The other end of the capacitor may be connected to one end of the first resistor, one end of the fifth resistor, a cathode of the first diode, and a terminal for turning-on/off control of the first power semiconductor switching element. The other end of the first resistor may be connected to one end of the second resistor. An anode of the first diode may be connected to one end of the third resistor. The other end of the third resistor may be connected to the other end of the first resistor. The other end of the fifth resistor may be connected to an anode of the second diode, and a cathode of the second diode may be connected to the current inflow terminal of the power semiconductor switching element of the switching unit. The other end of the sixth resistor may be connected to an anode of the third diode. A cathode of the third diode may be connected to the terminal for the turning-on/off control of the power semiconductor switching element of the switching unit, one end of the seventh resistor, and a current outflow terminal of the second power semiconductor switching element. The other end of the seventh resistor may be connected to the other end of the fourth resistor and a terminal for turning-on/off control of the second power semiconductor switching element. Also, the current outflow terminal of the second power semiconductor switching element may be connected to one end of the eighth resistor, and the other end of the eighth resistor may be connected to the current outflow terminal of the second power semiconductor switching element.

[0019] In yet another exemplary embodiment, the power semiconductor switching element may be selected from on/off controllable switching elements such as an insulated gate bipolar transistor, a MOSFET, and a bipolar junction transistor.

[0020] In still yet another exemplary embodiment, a value of a first capacitor of the gate drive circuit and a value of the first resistor may be set to adjust a maximum dead time of the gate drive circuit.

[0021] In a further exemplary embodiment, a value of a first capacitor of the gate drive circuit of the first switch leg may be designed to be smaller than a value of a first capacitor of the gate drive circuit of the second switch leg, and a value of a first resistor of the gate drive circuit of the first switch leg may be designed to be smaller than a value of a first resistor of the gate drive circuit of the second switch leg, such that an operation frequency range of the power semiconductor switching element of the gate drive circuit of the first switch leg is wider than an operation frequency range of the power semiconductor switching element of the gate drive circuit of the second switch leg.

[0022] In an exemplary embodiment, the isolated resonant converter may further include a controller that applies a gate drive signal to the gate drive circuit.

[0023] In another exemplary embodiment, the controller may include: a switching frequency generating unit generating a switching frequency necessary for an operation of the first and second switch legs; and an operation determining unit stably controlling turning-on/off of the switching frequency generating unit.

[0024] In still another exemplary embodiment, the switching frequency generating unit may be configured to include a voltage controller, a current controller, a switching frequency modulator, a diode unit determining a voltage applied to the switching frequency modulator, a switching frequency phase shifter, and an AND gate. The voltage controller may compare a sensed output DC voltage value with a targeted reference voltage value, and when the sensed value is smaller than the reference voltage value, may output a voltage proportional to a different between the sensed value and the reference voltage value. The current controller may compare a sensed output DC current value with a targeted reference current value, and when the sensed value is smaller than the reference current value, may output a voltage proportional to a different between the sensed value and the reference current value. The diode unit may compare output voltage values from the voltage controller and the current controller, and may apply smaller one of the output voltages to the switching frequency modulator. The switching frequency modulator may output a switching frequency in proportion to a magnitude of a signal applied from the voltage controller or the current controller through the diode unit. The switching frequency phase shifter may receive the switching frequency from the switching frequency modulator to generate a frequency phase-shifted from the switching frequency according to the number of the first and second switch legs. Also, the AND gate may be provided in plurality according to the number of the first and second switch legs and may receive the frequency from the switching frequency phase shifter through one terminal by each AND gate to take charge of each switch leg.

[0025] In yet another exemplary embodiment, the operation determining unit may include an SR latch, a comparator, and an OR gate. The comparator may compare a value sensed from an output terminal with a predetermined reference value, and when the sensed value is greater than the predetermined reference value, may output a high output signal. The OR gate may receive a protection circuit-related signal including a value outputted from the comparator and outputs the protection circuit-related signal to an R terminal of the SR latch for turning off control of a power supply. Also, the SR latch may receive a power application signal from an S terminal to perform the turning-on/off of the power supply. A voltage of a Q terminal may be determined by the signals of the S terminal and the R terminal, and thus the SR latch may perform the turning-on/off of the power supply using the voltage of the Q terminal.

[0026] Other aspects and exemplary embodiments of the invention are discussed infra.

[0027] Further, a gate drive circuit is configured to include a first power semiconductor switching element, a second power semiconductor switching element, first to third diodes, and first to eighth resistors, and a capacitor; to distinguish a charge path and a discharge path of a current applied to the terminal for the turning-on/off control of the power semiconductor switching element of the switching unit, a gate drive signal is inputted into the current outflow terminal of the first power semiconductor switching element, and one end of the sixth resistor is connected to the current outflow terminal of the first power semiconductor switching element; the current outflow terminal of the first power semiconductor switching element is connected to one end of the capacitor, one end of the fourth resistor, one end of the second resistor, and the current outflow terminal of the power semiconductor switch element of the switching unit; the other end of the capacitor is connected to one end of the first resistor, one end of the fifth resistor, a cathode of the first diode, and a terminal for turning-on/off control of the first power semiconductor switching element; the other end of the first resistor is connected to one end of the second resistor; an anode of the first diode is connected to one end of the third resistor; the other end of the third resistor is connected to the other end of the first resistor; the other end of the fifth resistor is connected to an anode of the second diode, and a cathode of the second diode is connected to the current inflow terminal of the power semiconductor switching element of the switching unit; the other end of the sixth resistor is connected to an anode of the third diode; a cathode of the third diode is connected to the terminal for the turning-on/off control of the power semiconductor switching element of the switching unit, one end of the seventh resistor, and a current outflow terminal of the second power semiconductor switching element; the other end of the seventh resistor is connected to the other end of the fourth resistor and a terminal for turning-on/off control of the second power semiconductor switching element; and the current outflow terminal of the second power semiconductor switching element is connected to one end of the eighth resistor, and the other end of the eighth resistor is connected to the current outflow terminal of the second power semiconductor switching element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The above and other features of the present invention will now be described in detail with reference to certain exemplary embodiments thereof illustrated the accompanying drawings which are given hereinbelow by way of illustration only, and thus are not limitative of the present invention, and wherein:

FIG. 1 is a view illustrating an internal configuration of a resonant converter according to an exemplary embodiment of the present invention;

FIG. 2 is a circuit view illustrating a multi-phase resonant converter;

FIG. 3 is a view illustrating an internal circuit of a gate drive circuit;

FIG. 4 is a view illustrating an operation of a gate drive circuit upon application of a turn-on signal when voltages at both terminals of a switch element do not correspond to a zero voltage condition;

FIG. 5 is a view illustrating a driving operation of a gate drive circuit upon application of a turn-on signal when voltages at both terminals of a switch element correspond to a zero voltage condition;

FIG. 6 is a view illustrating an operating state of a gate drive circuit when a turn-off signal is applied from a controller to a gate driver circuit;

FIG. 7 is a view illustrating a simulation operation result of a resonant converter according to an exemplary embodiment of the present invention;

FIG. 8 is a view illustrating a configuration of a controller generating a switching frequency used in a resonant converter according to an exemplary embodiment of the present invention;

FIG. 9 is a waveform illustrating a drive signal waveform a power semiconductor switching element during an unstable control in a transient state of turning-on/off operation of a controller power device;

FIG. 10 is a waveform illustrating a drive signal waveform of a power semiconductor switching element after a stable control in a transient state of turning-on/off operation of a controller power device;

FIG. 11 is a view illustrating control characteristics of a resonant converter according to a switching frequency, which shows the resonant converter operating in a continuous conduction region has to increase the switching frequency to lower an output voltage; and

FIG. 12 is a view illustrating a loss of an Insulated Gate Bipolar Transistor (IGBT) when an output power (voltage and current) is lowered for the use at a light load region.

[0029] Reference numerals set forth in the Drawings includes reference to the following elements as further discussed below:

100 : gate drive circuit
111 : first capacitor
121 : first resistor
122 : fifth resistor
123 : sixth resistor
124 : fourth resistor
125 : eighth resistor
126 : third resistor
131 : first MOSFET
132 : second MOSFET
141 : first diode
142 : second diode
143 : third diode
200 : insulated gate bipolar transistor (IGBT)
300 : diode
400 : capacitor
500 : resonant inductor
600 : resonant capacitor
700 : transformer
800 : controller
810 : switching frequency generating unit
811 : voltage controller
812 : current controller
813 : diode unit
814 : switching frequency modulator
815 : switching frequency phase shifter
816 : AND gate
820 : operation determining unit
821 : comparator
822 : OR gate
823 : SR latch

[0030] It should be understood that the accompanying drawings are not necessarily to scale, presenting a somewhat simplified representation of various exemplary features illustrative of the basic principles of the invention. The specific design features of the present invention as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes will be determined in part by the particular intended application and use environment.

[0031] In the figures, reference numbers refer to the same or equivalent parts of the present invention throughout the several figures of the drawing.

DETAILED DESCRIPTION

[0032] Hereinafter reference will now be made in detail to various embodiments of the present invention, examples of which are illustrated in the accompanying drawings and described below. While the invention will be described in conjunction with exemplary embodiments, it will be understood that present description is not intended to limit the invention to those exemplary embodiments. On the contrary, the invention is intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

[0033] The above and other features of the invention are discussed infra.

[0034] Hereinafter, exemplary embodiments of the present invention will be described in detail with reference to the accompanying drawings so that those skilled in the art can easily carry out the present invention.

[0035] FIG. 1 is a view illustrating an internal configuration of a resonant converter according to an exemplary embodiment of the present invention.

a resonant converter according to an exemplary embodiment of the present invention may include a gate drive circuit 100, an Insulated Gate Bipolar Transistor (IGBT) 200, a diode 300, a capacitor 400, a resonant inductor (Lr) 500, a resonant capacitor (Cr) 600, and a transformer 700.

[0036] The resonant converter according to the exemplary embodiment of FIG. 1, comprises three branches and each branch is formed with two switch elements connected in series to form three branches. These three branches may be called switch legs. The switch leg may be a circuit in which a pair of switching units including the gate drive circuit 100, the Insulated Gate Bipolar Transistor (IGBT) 200, the diode 300, and the capacitor 400 are connected in series.

[0037] The switch element used in the switching unit of the resonant converter according to the exemplary embodiment of the present invention may include the IGBT 200. The IGBT 200 may be a part that can convert a DC voltage into an AC voltage through frequency switching.

[0038] Accordingly, three switch legs of the resonant converter may be a 3-phase half bridge resonant inverter in which three single-phase half bridge inverters are combined.

[0039] However, the present invention is not necessarily limited to the IGBT 200, and a power semiconductor switching element such as a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) or a bipolar junction transistor that is possible to control turning-on/off can be used.

[0040] In case of the power semiconductor switching element, since the flow of electrons is opposite to the direction of a current, a collector or a drain may be referred to as a current inflow terminal, and a source or an emitter may be referred to as a current outflow terminal. Also, a gate or a base may be referred to as a terminal for on/off switching control.

[0041] The resonant inductor 500, the resonant capacitor 600, and the primary side of the transformer 700 may be connected in series to a connection part of the IGBTs 200. The resonant inductor 500 and the resonant capacitor 600 may determine a resonant frequency with a resonant tank parameter of each switch leg, and may allow the IGBT 200 to perform soft switching. The transformer 700 may vary a voltage and a current to control an output power (voltage and current).

[0042] G1 to G6 applied to the gate driver circuits 100, which is a frequency variable signal for controlling the output voltage into a desired value, may be used as an input of the gate drive circuit in the resonant converter according to the exemplary embodiment of the present invention.

[0043] The gate driver circuit 100 may sense the voltages on the both terminals, i.e. the collector and emitter of the IGBT 200. When the voltage of the capacitor 400 of the snubber circuit connected in parallel to the IGBT 200 is not zero, the gate driver circuit 100 may operate in dead time mode, allowing the semiconductor device not to be turned on even though the gate signals G1 to G6 are introduced. Also, when the capacitor 400 of the snubber circuit is discharged and becomes a zero voltage condition, the gate drive circuit 100 may turn on the IGBT 200, implementing the zero voltage switching and reducing the switching loss. Here, the dead time denotes an elapsed time until the change of the output is recognized after the change of the input. That is, when the gate drive circuit 100 operates in dead time mode, the input signal may not affect the output. Accordingly, it can be considered that the input is ignored.

[0044] Each terminal of the gate drive circuit 100 may be called a first terminal, a second terminal, and a third terminal according to the connection parts with the switching element. For example, when the switching element is the IGBT 200, a part at which the gate drive circuit 100 is connected to the collector terminal of the IGBT 200 may be called the first terminal, and a part at which the gate drive circuit 100 is connected to the emitter terminal of the IGBT 200 may be called the second terminal. Also, a part at which the gate drive circuit 100 is connected to the gate terminal of the IGBT 200 may be called the third terminal.

[0045] The resonant converter according to the exemplary embodiment of the present invention can easily sense the zero voltage condition of the switch using the gate drive circuit, and high efficiency operation can be performed in all load ranges without a separate configuration of a complicated control circuit.

[0046] Also, since the high precision output control is possible with a relatively small output filter component, even though an arc occurs at the output terminal, arch energy delivered from the converter to the load can be minimized, efficiently protecting a load vulnerable to the arc. This means that precision control is possible by the resonant converter according to the exemplary embodiment of the present invention without increasing the capacitor value of the output terminal even in case of special power devices such as gyrotron, klystron, magnetron, and radar, which require control precision degree of about 0.1% or less in the source power value.

[0047] The capacitor 400 connected in parallel to the diode 300 may serve as a snubber circuit. The snubber circuit may alleviate the rapid change of voltage and may reduce a loss of the turn-on/off.

[0048] The resonant converter according to the exemplary embodiment of the present invention may show a high efficiency by converting power only using a single switch leg at the light load in which low power is used and other switch legs together within the rated load range by sensing the voltage of the capacitor of just this snubber circuit. For this, the switch leg of a region A may be designed to be smaller than other switch legs in the value of the capacitor 400 of the snubber circuit.

[0049] The reason why the switch leg of the region A is designed to be smaller than other switch legs in the value of the capacitor 400 of the snubber circuit is as follows.

[0050] As shown in FIG. 9, a light load less than the rated load is applied to the resonant converter, power consumed in the light load may be smaller than that in a medium load or a high load. Accordingly, the resonant converter may output a low power (voltage or current), and for this, the switching frequency applied to the switching element may be adjusted into high.

[0051] However, as the switching frequency becomes high, a switching loss of switching elements including the IGBT 200 may rapidly increase. Furthermore, the IGBT 200 may be damaged by burning. Accordingly, there is a difficulty in that a typical resonant converter used in a continuous conduction mode needs to be provided with an addition circuit for controlling the gate driving signal itself to be used in all load ranges (from no load to full load) from no load condition to rated load condition.

[0052] Here, the rated load denotes a load that is designed in consideration of the capacity of the resonant converter. That is, when the resonant converter according to the exemplary embodiment of the present invention is designed to drive a magnetron of about 50 KW, the rated load may be 50 KW. Accordingly, when a magnetron with a value smaller than about 50 KW is connected, the value can be referred to as the light load compared to the rated load. Also, when a load is not applied to the output terminal of the resonant circuit, it can be referred to as no load.

[0053] When a light load is connected, the resonant converter according to the exemplary embodiment of the present invention intends to ensure the operation of the resonant converter in all voltage and current output ranges by operating only a single switch leg to take charge of the light load.

[0054] For this, in the resonant converter according to the exemplary embodiment of the present invention, the capacitor 400 of the snubber circuit of one of a plurality of switch legs may be designed to be smaller than the capacitor 400 of the snubber circuit of other switch legs.

[0055] Since the charge capacity becomes smaller when the capacitor 400 is small, the capacitor 400 may be charged and discharged at a faster speed. Accordingly, in the switch leg to take charge of the light load operation, the gate drive circuit 100 may quickly sense the zero voltage of the capacitor 400 of the snubber circuit, thereby performing switching more quickly. That is, even when a high switching frequency signal is used to operate the light load, a switching load can be reduced by an instantaneous response thereto.

[0056] On the other hand, the other switch legs of may be designed to be larger than the switch leg taking charge of the light load in the value of the capacitor 400 of the snubber circuit. Accordingly, since the other switch legs are difficult to become the zero voltage in a fast switching frequency, the other switch legs may operate in dead time mode in which the switching is not performed.

[0057] Therefore, the operation region can be extended such that operation is possible in all load ranges while reducing the switching loss.

[0058] That is, in a related art, although the resonant converter can be designed to operation in all load ranges by sensing a load region of a power device and interrupting a gate signal by a controller, the circuit configuration is complicated, and the reliability is low. Also, in case of low frequency switching, an audible noise may occur.

[0059] Accordingly, in the resonant converter according to the exemplary embodiment of the present invention, the above limitation can be overcome by designing the snubber capacitor value of one of a plurality of switch legs to be smaller than the capacitor value of the snubber circuit of the other switch legs.

[0060] Also, in the resonant converter according to the exemplary embodiment of the present invention, since the switch leg taking full charge of the light load and the other switch legs together operate during the rated load operation, high precision control of the output voltage can be performed by the operation of these two types of switching leg. Also, since the output voltage is controlled by the high frequency switching operation of only a single switch leg, the ripple of the output voltage can be minimized, and the high precision control can be achieved. Accordingly, due to this high precision control, the optimal design of the output filter can be achieved without increasing the output filter component (output capacitor), and thus, energy delivered to the load upon occurrence of arc can be minimized, efficiently protecting the load.

[0061] FIG. 2 is a circuit view illustrating a multi-phase resonant converter.

[0062] The basic concept of the resonant converter of FIG. 2 is similar to that of the resonant converter of FIG. 1.

[0063] The resonant converter of FIG. 1 is designed expecting three-phase, whereas the resonant converter of FIG. 2 is designed expecting multi-phase. However, the resonant converter of FIG. 1 is similar to the resonant converter of FIG. 2 in that one of a plurality of switch legs is designed to take charge of the light load.

[0064] The switch leg to take charge of the light load, which is indicated in the block A, may be designed to include a snubber capacitor with a small capacitor so as to be suitable for a fast switching frequency according to a light load condition, and a gate driver circuit may also be designed to have dead time according to the value of this small snubber capacitor.

[0065] Accordingly, the resonant converter according to the exemplary embodiment of the present invention may be designed such that one switch leg, i.e., single phase inverter operates in a high frequency switching state taking charge of the light load, and the other two switch legs have a maximum dead time so as to take charge of a rated load condition. Thus, the resonant converter may be configured to include a multi-phase inverter (switch leg) having a certain phase difference. One of the inverters may be designed to operate at a higher switching frequency than the other inverters to implement a hybrid type of multi-phase inverter. Accordingly, the resonant inverter according to the exemplary embodiment of the present invention may also be referred to as a hybrid resonant converter.

[0066] Due to this configuration, all inverters may operate with a phase difference at a high load operation region, and thus high precision output control can be achieved. Also, in a light load region, only a separately designed single inverter may operate at a high switching frequency to implement the high precision control, and the other inverter switches do not perform switching operation, enabling the high efficient operation due to no loss.

[0067] In the resonant converter according to the exemplary embodiment of the present invention, since all switch legs operate with a phase difference at the rated load region, and only a separate switch leg operates at a high switching frequency in the light load or no load region, high precision control can be achieved while keeping the component of a filter capacitor of an output terminal small.

[0068] Therefore, even in case of devices such as gyrotron, klystron, magnetron, and radar power device that need high precision output control, since the high precision control can be achieved without increasing the size of the filter capacitor, the energy of the filter capacitor that is delivered to a load terminal upon occurrence of arc can be minimized while keeping the ripple of the output voltage small.

[0069] FIG. 3 is a view illustrating an internal circuit of a gate drive circuit.

[0070] In the gate drive circuit 100 according to the exemplary embodiment of the present invention, since the dead time can be flexibly designed, the gate drive circuit 100 can also be referred to as a gate drive circuit with flexible dead time.

[0071] The gate drive circuit 100 may be configured to include a resistor, a diode, a capacitor, and a MOSFET element.

[0072] In FIG. 3, V_{pulse} denotes a signal applied from the controller to the gate drive circuit 100.

[0073] The purpose of the gate drive circuit 100 is to sense from the V_{pulse} whether or not the voltages of both terminals of the switching element become zero and thus apply a gate signal to the switching element.

[0074] For this, the gate drive circuit 100 of the resonant converter may set a first capacitor 111 and a first resistor 121 to operate a first MOSFET element 131 with the maximum dead time. The first MOSFET element 131 may apply a gate voltage to the IGBT 200 with a certain dead time when a turn-on signal is applied from the controller. A second MOSFET element 132 may be an element for pulling down the gate voltage when a turn-off signal is applied from the controller. Also, a second diode 142 may be used to sense the voltage of the collector of the IGBT that is used as a switching element.

[0075] Hereinafter, a concrete operation method of the gate drive circuit 100 will be described in detail with reference to the accompanying drawings.

[0076] FIG. 4 is a view illustrating an operation of a gate drive circuit upon application of a turn-on signal when voltages at both terminals of a switch element do not correspond to a zero voltage condition.

[0077] When the voltage of the both terminals of the IGBT 200 is not the zero voltage and V_{pulse} that is a gate drive signal is inputted from the controller, the first capacitor 111 may be slowly charged through the first resistor 121. This is because a current flows through the capacitor 111 and the first resistor 121 because a current cannot flow through the second diode 142 because the voltage of the collector of the IGBT 200 is not zero.

[0078] FIG. 5 is a view illustrating a driving operation of a gate drive circuit upon application of a turn-on signal when voltages at both terminals of a switch element correspond to a zero voltage condition.

[0079] When the both terminals of the IGBT 200 become the zero voltage, the second diode 142 may become a forward bias. In this case, since the value of a fifth resistor 122 is designed to be smaller than the value of the first resistor 121, the first capacitor 111 may be rapidly charged through the fifth resistor 122 and the second diode 142.

[0080] When the voltage of the first capacitor 111 is charged, the voltages of the both terminals of the capacitor 111 also rise. When the voltages of the both terminals of the first capacitor 111 are charged greater than or equal to a threshold voltage of the gate terminal of the first MOSFET element 131, the first MOSFET element 131 may be turned on.

[0081] When the first MOSFET element 131 is turned on, the gate drive signal of the controller may be applied to the gate terminal of the IGBT 200 through a sixth resistor 123 and a third diode 143.

[0082] FIG. 6 is a view illustrating an operating state of a gate drive circuit when a turn-off signal is applied from a controller to a gate driver circuit.

[0083] When a turn-off signal is applied, a voltage may be applied to the gate terminal of the second MOSFET element 132 of the gate drive circuit to turn on the second MOSFET element 132. Accordingly, the current applied to the gate terminal of the IGBT 200 may rapidly flow from the source terminal to the drain terminal of the second MOSFET element 132 and then may be discharged to the ground through an eighth resistor 125.

[0084] Similarly, as the turn-off signal is applied from the controller, the voltage charged in the first capacitor 111 may also be discharged through the third resistor 126 and the first diode 141. As the first capacitor 111 is discharged, the first MOSFET element 131 may be turned off, and thus the IGBT 200 may also be switched off.

[0085] Since the gate drive circuit of the resonant converter according to the exemplary embodiment of the present invention is provided with a separate MOSFET element to take charge of turn-off of the IGBT 200, the first capacitor 111 may be allowed to be charged from the zero voltage to the threshold voltage at which the first MOSFET element 131 is turned on instead of being charged from a minus (-) voltage to a plus (+) voltage. Accordingly, since the first capacitor 111 need not be charged from a minus (-) voltage to the threshold voltage of the first MOSFET element 131, power applied to the gate drive signal can be saved. Also, since the gate charge and discharge paths are distinguished, MOSFET heating can be reduced during the high frequency switching operation.

[0086] As above, the operation state of the gate drive circuit 100 has been described with reference to the drawing.

[0087] The values of the first resistor 121 and the first capacitor 111 of the gate drive circuit 100 of the switch leg to take charge of a light load may be designed differently from the values of the gate drive circuit 100 of other switch legs for faster switching.

[0088] In other words, the value of the first capacitor 111 of the gate drive circuit 100 of the switch leg to take charge of a light load may be set to a smaller value than the values of other switch legs. Also, the value of the first resistor 121 may be set smaller than the values of the other switch legs. Since the time constant decreases due to the selection of small values of the resistor and the capacitor, the response is possible even for the high frequency switching unlike other switch legs.

[0089] Accordingly, in the gate drive circuit 100 of the resonant converter according to the exemplary embodiment of the present invention, the dead time can be flexibly controlled. However, for the selection of such values, it is desirable to select dead time value enough to turn on the first MOSFET element 131.

[0090] FIG. 7 is a view illustrating a simulation operation result of a resonant converter according to an exemplary embodiment of the present invention.

[0091] Referring to FIG. 7, in the resonant converter according to the exemplary embodiment of the present invention, although the switching frequency is applied at about 60 KHz or more to output low power (voltage or current), the circuit may not be damaged by burning.

[0092] Accordingly, it can be seen that it is possible to control a wide load range from a light load to a full load.

[0093] FIG. 8 is a view illustrating a configuration of a controller generating a switching frequency used in a resonant converter according to an exemplary embodiment of the present invention.

[0094] A controller 800 may generate a switching frequency necessary for each switch leg, and may roughly include a switching frequency generating unit 810 that generates a switching frequency necessary for the operation of first and second switch legs and an operation determining unit 820 that stably controls the turning-on/off of the switching frequency generating unit 810.

[0095] The switching frequency generating unit 810 may include a voltage controller 811, a current controller 812, a diode unit 813, a switching frequency modulator 814, a switching frequency phase shifter 815, and an AND gate 816.

[0096] The voltage controller 811 and the current controller 812 may be parts that generate control signals by sensing the output voltage and current.

[0097] More specifically, the voltage controller 811 may receive a value $V_{sensing}$ obtained by sensing a DC voltage of the output terminal, and may compare the value $V_{sensing}$ with a reference voltage value V_{ref} that the resonant converter intends to output. When the value $V_{sensing}$ is lower than the reference voltage value V_{ref}, the voltage controller 811 may output a voltage value proportional to a difference between the two voltage values $V_{sensing}$ and V_{ref} to allow the resonant converter to output the reference voltage value aimed by the resonant converter. Also, the current controller 812 may receive a value $I_{sensing}$ obtained by sensing a DC current of the output terminal, and may compare the value $I_{sensing}$ with a reference current value I_{ref} that the resonant converter intends to output. When the value $I_{sensing}$ is lower than the reference voltage value I_{ref}, the current controller 812 may output a current value proportional to a difference between the two current values $I_{sensing}$ and I_{ref} to allow the resonant converter to output the reference current value aimed by the resonant converter.

[0098] The diode unit 813 may receive the values of the voltage controller 811 and the current controller 812, and may allow smaller one of the values to be applied to the switching frequency generating unit 810.

[0099] For this, the diode unit 813 may be configured such that the anodes of two diodes contact each other. That is, the cathode of one diode D_{or1} may be connected to the output terminal of the voltage controller 811, and the anode thereof may be connected to the anode of the other diode D_{or2}. Also, the cathode of the other diode D_{or2} may be connected to the output terminal of the current controller 812, and the switching frequency generating unit 810 may be connected to the anode side at which two diodes contact each other.

[0100] Due to this configuration, the diode unit 813 may allow smaller one of the values of the voltage controller 811 and the current controller 812 to be applied to the switching frequency generating unit 810. As a result, when a fine error occurs in either of the two values after reaching the reference voltage value and the reference current value, the fine error may be delivered to the switching frequency generating unit 810 to allow the switching frequency signal applied to the gate drive circuit 100 to be controllable in real-time.

[0101] The switching frequency generating unit 810 may be a part that modulates the frequency in proportion to the voltage V_c applied from the diode unit 813. That is, depending on a load connected to the resonant converter, when no load or a light load requiring a low voltage is connected to the load terminal, the switching frequency generating unit 810 may generate a high switching frequency necessary for reducing the voltage value that is outputted. Also, when a rated load or a load that the resonant converter determines as equal to or greater than a light load or no load is connected to the load terminal, the switching frequency generating unit 810 may serve to generate a low switching frequency.

[0102] The switching frequency phase shifter 815 may be a part that generates a switching frequency according to the number of the first and second legs. Here, the switching frequency may have a phase difference such that each switch leg can appropriately use the frequency generated by the switching frequency modulator 814. The switching frequency phase shifter 815 may be implemented by a digital circuit such as a Johnson counter.

[0103] The switching frequency signal generated in the switching frequency phase shifter 815 may be inputted into one terminal of the AND gates 816 to take charge of each switch leg. The AND gates 816 may take charge of one switch leg, respectively.

[0104] Each gate signal that is modulated in frequency and phase by passing the switching frequency modulator 814 and the switching frequency phase shifter 815 may be inputted into each gate drive circuit to be used to drive one switch leg.

[0105] The controller 800 and the operation determining unit 820 may be configured to include a comparator 821 including an operational amplifier, an OR gate 822, and an SR latch 823.

[0106] The comparator 821 of the operation determining unit 820 may compare a set value determined as abnormal with a value sensed from the output terminal. When the sensed value is larger than the set value, the comparator 821 may generate a positive output to input the positive output into the OR gate 822. The positive output value may also be referred to as a high output signal.

[0107] More specifically, the comparator 821 of FIG. 8 may receive a predetermined voltage value $V_{abnormal}$ assumable as an abnormal output value at the output terminal and a sensed value $V_{protection}$ received from the output terminal, and when the sensed value $V_{protection}$ is applied as a value larger than the predetermined voltage value $V_{abnormal}$ considered as abnormal, the comparator 821 may generate a positive output and input the positive output into the OR gate 822.

[0108] The OR gate 822 may receive abnormal signals such as temperature and current of the output terminal that are inputted from the comparator 821 or directly inputted, and when an abnormality occurs in any one of the abnormal signals, may send an output to an R terminal of the SR latch 823.

[0109] The signals inputted into the OR gate 822 may include abnormal voltage, current, and temperature, or a power off signal. These signals may be directly applied to the OR gate 822, and may also be inputted into the OR gate 822 after undergoing a process of being compared with a predetermined value by the comparator 821. These abnormal signals inputted into the OR gate 822 may also be referred to as a protection circuit-related signal.

[0110] The SR latch 823 may be a part that determines the operation of the whole switching frequency generating unit 810 using a power signal and the signal inputted from OR gate 822.

[0111] For this, the SR latch 823 may receive the power signal (Power On) for driving the controller 800 through an S terminal, and may receive the abnormal signals outputted from the OR gate 822 through an R terminal.

[0112] A Q terminal Venable that is a non-inverting output of the SR latch 823 may be inputted into an operation terminal V_{sfm_ic} of the switching frequency modulator 814 of the switching frequency generating unit 810, an operation terminal V_{ps_ic} of the switching frequency phase shifter 815, and the other input terminal V_{gate} of the AND gate 816. When a high value is inputted into these terminals, each part may normal operate. On the other hand, when a low value is inputted, each part may stop operating.

[0113] The truth table of the SR latch 823 is as follows.

Functional Table

[0114]

Table 1

S	R	Q	Q'	
1	0	1	0	Set State
0	0	1	0	
0	1	0	1	Reset State
0	0	0	1	
1	1	0	0	Undefined

[0115] Accordingly, in the SR latch 823 of the operation determining unit 820 of the controller 800 of the resonant converter, when power is applied and there is no abnormality on the output terminal, the SR latch 823 may allow the switching frequency normally generated by the switching frequency generating unit 810 to be applied to the gate drive circuit 100.

[0116] However, when there is an abnormality such as voltage, current, or rapid temperature rise on the output terminal, these value may be inputted into the R terminal of the SR latch 823 through the OR gate 822. Accordingly, the output value of the Q terminal of the SR latch 823 may become low (0), and thus, the operation of the switching frequency generating unit 810 may stop.

[0117] Accordingly, the resonant converter can be prevented from being damaged by the abnormality of the output terminal.

[0118] In a related art, since the output of the switching frequency modulator 814 implemented using analog elements such as resistors and capacitors is directly inputted into the gate drive circuit 100, a transient abnormal waveform can be formed upon turning-on/off of the power supply, thereby damaging the IGBT 200. However, in the exemplary embodiment of the present invention, since the signal Venable that operates the switching frequency modulator 814, the switching frequency phase shifter 815, and the AND gate 816 is applied through a circuit designed based on digital elements such as a latch, a switching frequency can be stably generated without an abnormality of a transient state even upon turning-on/off of the power supply.

[0119] FIG. 9 is a waveform illustrating a drive signal waveform a power semiconductor switching element during an unstable control in a transient state of turning-on/off operation of a controller power device.

[0120] It can be seen that the drive signal waveform of the power semiconductor switching element is unstably supplied in the transient state of turning on/off.

[0121] FIG. 10 is a waveform illustrating a drive signal waveform of a power semiconductor switching element after a stable control in a transient state of turning-on/off operation of a controller power device.

[0122] Compared with FIG. 9, it can be seen that stable control is enabled even in the transient state of turning on/off.

[0123] A special power source used in an electron accelerator or a radar requires high precision output control of high voltage DC power. These apparatuses require control precision degree of about 0.1% or less. Recently, domestic and foreign enterprises are developing and using a separate power source that can generate the maximum output and perform precision control, but cost for manufacturing these power supplies is expensive. Also, since a series or parallel operation of two power supplies is needed, it is complicate to control, and it is difficult to secure reliability. Also, since the control is complicated, it is difficult to secure reliability upon occurrence of arc.

[0124] Accordingly, in case of a typical high voltage power source, a method of limiting an operable minimum output voltage range is used to achieve a high efficiency at a rated load.

[0125] However, a resonant converter according to an exemplary embodiment of the present invention, which can be called a hybrid-type inverter, can implement a high precision control power supply with a single converter, and can achieve a high efficiency at a rating. Furthermore, the resonant converter is not limited in output voltage control range.

[0126] Accordingly, the resonant converter can be efficiently applied as a DC source of a radar power supply and an electron accelerator power supply which require high precision and high voltage output control. Also, the resonant converter can be applied to the power application field that needs to minimize the voltage droop and the ripple of the output voltage like gyrotron, klystron, and magnetron and limit energy delivered to the load terminal upon occurrence of arc. Besides, the resonant converter can be variously utilized in battery charges, high voltage capacitor chargers, and general-purpose DC power supplies.

[0127] As described above, a high efficiency resonant converter with an extensive load range according to an embodiment of the present invention has the following effects.

[0128] First, the DC/DC converter can an extensive load range by including a single switch leg that takes full charge of a light load operation. Accordingly, the DC/DC converter can be applied to various industrial power supplies such as battery chargers, capacitor chargers, and plasma application power supplies, and general-purpose DC power supplies, which need to operate in all load ranges (from no load to full load).

[0129] Second, since only the signal switch leg operates and other switch legs do not operate during the light load operation by a high switching frequency, a switching loss does not occur in the other switch legs, thereby maintaining a high input vs. output efficiency.

[0130] Third, since the switch leg taking charge of the light load and the other switch legs together operate at a rated load, a high efficiency can be maintained.

[0131] Fourth, since the capacitor value of the switch leg taking charge of the light load and the capacitor and resistor values of a gate drive circuit are adjusted, the control range of the switching frequency can be widely extended in spite of soft switching.

[0132] Fifth, since the dead time of the gate drive circuit of each switch leg can be freely designed and modified, a converter adaptable to various applications can be designed.

[0133] Sixth, since the dead time of the gate drive circuit for each switch leg can be set to the maximum dead time, and the time constant is adjusted according to the switching frequency, the zero voltage condition of a switching element can be efficiently sensed.

[0134] Seventh, in the gate drive circuit according to an exemplary embodiment of the present invention, since a separate MOSFET element that can quickly turn off the switching element is provided, a parasitic capacitor of the power semiconductor switching elements is charged from the zero voltage, not a minus (-) voltage. Accordingly, the power consumption for the gate driving power can be reduced, and since the gate charge and discharge paths are distinguished, MOSFET heating can be reduced during the high frequency switching operation.

[0135] Eighth, a high efficiency can be maintained at a rating by improving the waveform of a resonant current.

[0136] Ninth, the gate drive circuit according to an embodiment of the present invention can reduce a switching loss by easily sensing the zero voltage condition of a switch. Accordingly, the gate drive circuit can be applied to various power supplies such as a converter and an inverter.

[0137] Tenth, since all switch legs operate at the rated load region, and only a separate switch leg operates at a switching frequency of a high frequency in the light load region, high precision control can be achieved while keeping the component of a filter capacitor of an output terminal small. Therefore, even in case of devices such as gyrotron, klystron, magnetron, and radar power device that need high precision output control, since the high precision control can be achieved without increasing the size of the filter capacitor, the energy of the filter capacitor that is delivered to a load terminal upon occurrence of arc can be minimized while keeping the ripple of the output voltage small.

[0138] Eleventh, in a controller of a resonant converter according to an exemplary embodiment of the present invention, since a switching frequency can be stably generated even upon turning-on/off of a power supply a power semiconductor switch device such as an Insulated Gate Bipolar Transistor (IGBT) can be prevented from being damaged by burning.

[0139] The invention has been described in detail with reference to exemplary embodiments thereof. However, it will be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles of the invention, the scope of which is defined in the appended claims and their equivalents.

Claims

1. A resonant converter for converting a direct current (DC) into another direct current (DC) with a desired level, where when a light load is connected, only a single switch leg is operated to take charge of the light load,
   the resonant converter comprising a first switch leg (A) having one end connected to a positive terminal (+) of a DC power source (Vcd) and the other end connected to a negative terminal (-) of the DC power source (Vcd),
   the first switch leg (A) being operated as a single-phase half-bridge inverter at a first switching frequency under a light load condition and being operated together with one or more second switch legs at a second switching frequency being lower than the first switching frequency under a rated load condition or a high load condition;
   the one or more second switch legs having one end connected to the positive terminal (+) of the DC power source (Vcd) and the other end connected to the negative terminal (-) of the DC power source (Vcd) and being operated at the second switching frequency under a rated load condition;
   wherein the first and second switch legs each comprise two switching units connected in series, and each switching unit comprises:

   - a power semiconductor switching element (200);
   - a diode (300) comprising a cathode connected to a current inflow terminal of the power semiconductor switching element (200) and an anode connected to a current outflow terminal of the power semiconductor switching element (200);
   - a snubber capacitor (400) connected in parallel to the diode; and
   - a gate drive circuit (100) applying a switching signal to a terminal for turning-on/off control of the power semiconductor switching element (200),

   and wherein a value of the snubber capacitor (400) for preventing a rapid voltage increase of the first switch leg (A) is designed to be smaller than a value of the snubber capacitor (400) of the one or more second switch legs such that zero voltage sensing of the gate drive circuit (100) of the first switch leg (A) is faster than zero voltage sensing of the gate drive circuit of the second switch leg.

2. The resonant converter of claim 1, wherein the power semiconductor switching element (200) is selected from an insulated gate bipolar transistor, a MOSFET, and a bipolar junction transistor.

3. The resonant converter of claim 1, wherein:

   the gate drive circuit (100) is configured to comprise a first power semiconductor switching element (131), a second power semiconductor switching element (132), first to third diodes (141-143), and first to eighth resistor (121-126), and a capacitor (111);
   to distinguish a charge path and a discharge path of a current applied to the terminal for the turning-on/off control of the power semiconductor switching element (200) of the switching unit, a gate drive signal is inputted into the current outflow terminal of the first power semiconductor switching element (131), and one end of the sixth resistor (123) is connected to the current outflow terminal of the first power semiconductor switching element (131);
   the current outflow terminal of the first power semiconductor switching element (131) is connected to one end of the capacitor (111), one end of the fourth resistor (124), one end of the second resistor, and the current outflow terminal of the power semiconductor switch element (200) of the switching unit;
   the other end of the capacitor (111) is connected to one end of the first resistor (121), one end of the fifth resistor (122), a cathode of the first diode (141), and a terminal for turning-on/off control of the first power semiconductor switching element (131);
   the other end of the first resistor (121) is connected to one end of the second resistor;
   an anode of the first diode (141) is connected to one end of the third resistor (126);
   the other end of the third resistor (126) is connected to the other end of the first resistor (121);
   the other end of the fifth resistor (122) is connected to an anode of the second diode (142), and a cathode of the second diode (142) is connected to the current inflow terminal of the power semiconductor switching element (200) of the switching unit;
   the other end of the sixth resistor (123) is connected to an anode of the third diode (143);
   a cathode of the third diode (143) is connected to the terminal for the turning-on/off control of the power semiconductor switching element (200) of the switching unit, one end of the seventh resistor, and a current outflow terminal of the second power semiconductor switching el-

ement (132);
the other end of the seventh resistor is connected to the other end of the fourth resistor (124) and a terminal for turning-on/off control of the second power semiconductor switching element (132); and
the current outflow terminal of the second power semiconductor switching element (132) is connected to one end of the eighth resistor (125), and the other end of the eighth resistor (125) is connected to the current outflow terminal of the second power semiconductor switching element (132).

4. The resonant converter of claim 3, wherein the power semiconductor switching element (200) is selected from an insulated gate bipolar transistor, a MOSFET, and a bipolar junction transistor.

5. The resonant converter of claim 3, wherein a value of a first capacitor (111) of the gate drive circuit (100) and a value of the first resistor (121) is set to adjust a dead time of the gate drive circuit (100).

6. The resonant converter of claim 3, wherein a value of a first capacitor (111) of the gate drive circuit (100) of the first switch leg (A) is designed to be smaller than a value of a first capacitor of the gate drive circuit of the second switch leg, and a value of a first resistor (121) of the gate drive circuit (100) of the first switch leg (A) is designed to be smaller than a value of a first resistor of the gate drive circuit of the second switch leg, such that an operation frequency range of the power semiconductor switching element (200) of the gate drive circuit (100) of the first switch leg (A) is wider than an operation frequency range of the power semiconductor switching element of the gate drive circuit of the second switch leg.

7. The resonant converter of claim 1, further comprising a controller that applies a gate drive signal to the gate drive circuit (100).

8. The resonant converter of claim 7, wherein the controller comprises:

a switching frequency generating unit (810) generating a switching frequency necessary for an operation of the first (A) and second switch legs; and
an operation determining unit (820) stably controlling turning-on/off of the switching frequency generating unit (810).

9. The resonant converter of claim 8, wherein:

the switching frequency generating unit (810) is configured to comprise a voltage controller (811), a current controller (812), a switching frequency modulator (814), a diode unit (813) determining a voltage applied to the switching frequency modulator (814), a switching frequency phase shifter (815), and an AND gate (816);
the voltage controller (811) compares a sensed output DC voltage value with a targeted reference voltage value, and when the sensed value is smaller than the reference voltage value, outputs a voltage proportional to a different between the sensed value and the reference voltage value;
the current controller (812) compares a sensed output DC current value with a targeted reference current value, and when the sensed value is smaller than the reference current value, outputs a voltage proportional to a different between the sensed value and the reference current value;
the diode unit (813) compares output voltage values from the voltage controller (811) and the current controller (812), and applies smaller one of the output voltages to the switching frequency modulator (814);
the switching frequency modulator (814) outputs a switching frequency in proportion to a magnitude of a signal applied from the voltage controller (811) or the current controller (812) through the diode unit (813);
the switching frequency phase shifter (815) receives the switching frequency from the switching frequency modulator (814) to generate a frequency phase-shifted from the switching frequency according to a number of the first (A) and second switch legs; and
the AND gate (816) is provided in plurality according to the number of the first (A) and second switch legs and receives the frequency from the switching frequency phase shifter (815) through one terminal by each AND gate (816) to take charge of each switch leg.

10. The resonant converter of claim 8, wherein:

the operation determining unit (820) comprises an SR latch (823), a comparator (821), and an OR gate (822);
the comparator (821) compares a value sensed from an output terminal with a predetermined reference value, and when the sensed value is greater than the predetermined reference value, outputs a high output signal;
the OR gate (822) receives a protection circuit-related signal comprising a value outputted from the comparator (821) and outputs the protection circuit-related signal to an R terminal of the SR latch (823) for turning off control of a power supply; and

the SR latch (823) determines an output of a Q terminal using the signal inputted into the R terminal and a power application signal applied to an S terminal and input the output of the Q terminal into the switching frequency generating unit (810).

Patentansprüche

1. Resonanzwandler zum Umwandeln eines Gleichstroms (DC) in einen anderen Gleichstrom (DC) mit einem gewünschten Pegel, wobei, wenn eine leichte Last verbunden ist, nur ein einzelner Schaltzweig betrieben wird, um für die leichte Last die Verantwortung zu übernehmen,

    wobei der Resonanzwandler einen ersten Schaltzweig (A), von dem Ende mit einem positiven Anschluss (+) einer Gleichspannungsquelle (Vcd) verbunden ist und das andere Ende mit einem negativen Anschluss (-) der Gleichspannungsquelle (Vcd) verbunden ist, aufweist,
    wobei der erste Schaltzweig (A) als Einphasen-Halbbrücken-Inverter mit einer ersten Schaltfrequenz unter einer Bedingung leichter Last betrieben wird und zusammen mit einem oder mehreren zweiten Schaltzweigen mit einer zweiten Schaltfrequenz, die niedriger ist als die erste Schaltfrequenz, unter einer Nennlastbedingung oder einer Bedingung hoher Last betrieben wird;
    wobei von dem einen oder den mehreren zweiten Schaltzweigen ein Ende mit dem positiven Anschluss (+) der Gleichspannungsquelle (Vcd) verbunden ist und das andere Ende mit dem negativen Anschluss (-) der Gleichspannungsquelle (Vcd) verbunden ist, und sie mit der zweiten Schaltfrequenz unter einer Nennlastbedingung betrieben werden;
    wobei der erste und der zweite Schaltzweig jeweils zwei Schalteinheiten umfassen, die in Reihe geschaltet sind, und jede Schalteinheit umfasst:

        - ein Leistungshalbleiter-Schaltelement (200);
        - eine Diode (300) mit einer Kathode, die mit einem Stromzuflussanschluss des Leistungshalbleiter-Schaltelements (200) verbunden ist, und einer Anode, die mit einem Stromabflussanschluss des Leistungshalbleiter-Schaltelements (200) verbunden ist;
        - einen Dämpfungskondensator (400), der mit der Diode parallel geschaltet ist; und
        - eine Gate-Ansteuerschaltung (100), die ein Schaltsignal an einen Anschluss für die Ein/Aus-Schaltsteuerung des Leistungshalbleiter-Schaltelements (200) anlegt,

    und wobei ein Wert des Dämpfungskondensators (400) zum Verhindern einer schnellen Spannungszunahme des ersten Schaltzweigs (A) so ausgelegt ist, dass er kleiner ist als ein Wert des Dämpfungskondensators (400) des einen oder der mehreren zweiten Schaltzweige, so dass eine Nullspannungserfassung der Gate-Ansteuerschaltung (100) des ersten Schaltzweigs (A) schneller ist als eine Nullspannungserfassung der Gate-Ansteuerschaltung des zweiten Schaltzweigs.

2. Resonanzwandler nach Anspruch 1, wobei das Leistungshalbleiter-Schaltelement (200) aus einem Bipolartransistor mit isoliertem Gate, einem MOSFET und einem bipolaren Sperrschichttransistor ausgewählt ist.

3. Resonanzwandler nach Anspruch 1, wobei:

    die Gate-Ansteuerschaltung (100) so ausgelegt ist, dass sie ein erstes Leistungshalbleiter-Schaltelement (131), ein zweites Leistungshalbleiter-Schaltelement (132), erste bis dritte Dioden (141-143) und einen ersten bis achten Widerstand (121-126) und einen Kondensator (111) umfasst;
    um einen Aufladungspfad und einen Entladungspfad eines Stroms zu unterscheiden, der an den Anschluss für die Ein/Aus-Schaltsteuerung des Leistungshalbleiter-Schaltelements (200) der Schalteinheit angelegt wird,
    ein Gate-Ansteuersignal in den Stromabflussanschluss des ersten Leistungshalbleiter-Schaltelements (131) eingegeben wird und ein Ende des sechsten Widerstandes (123) mit dem Stromabflussanschluss des ersten Leistungshalbleiter-Schaltelements (131) verbunden wird;
    der Stromabflussanschluss des ersten Leistungshalbleiter-Schaltelements (131) mit einem Ende des Kondensators (111), einem Ende des vierten Widerstandes (124), einem Ende des zweiten Widerstandes und dem Stromabflussanschluss des Leistungshalbleiter-Schaltelements (200) der Schalteinheit verbunden wird;
    das andere Ende des Kondensators (111) mit einem Ende des ersten Widerstandes (121), einem Ende des fünften Widerstandes (122), einer Kathode der ersten Diode (141) und einem Anschluss für die Ein/Aus-Schaltsteuerung des ersten Leistungshalbleiter-Schaltelements (131) verbunden wird;
    das andere Ende des ersten Widerstandes (121) mit einem Ende des zweiten Widerstandes verbunden wird;

eine Anode der ersten Diode (141) mit einem Ende des dritten Widerstandes (126) verbunden wird;
das andere Ende des dritten Widerstandes (126) mit dem anderen Ende des ersten Widerstandes (121) verbunden wird;
das andere Ende des fünften Widerstandes (122) mit einer Anode der zweiten Diode (142) verbunden wird und eine Kathode der zweiten Diode (142) mit dem Stromzuflussanschluss des Leistungshalbleiter-Schaltelements (200) der Schalteinheit verbunden wird;
das andere Ende des sechsten Widerstandes (123) mit einer Anode der dritten Diode (143) verbunden wird;
eine Kathode der dritten Diode (143) mit dem Anschluss für die Ein/Aus-Schaltsteuerung des Leistungshalbleiter-Schaltelements (200) der Schalteinheit, einem Ende des siebten Widerstandes und einem Stromabflussanschluss des zweiten Leistungshalbleiter-Schaltelements (132) verbunden wird;
das andere Ende des siebten Widerstandes mit dem anderen Ende des vierten Widerstandes (124) und einem Anschluss für die Ein/Aus-Schaltsteuerung des zweiten Leistungshalbleiter-Schaltelements (132) verbunden wird; und
der Stromabflussanschluss des zweiten Leistungshalbleiter-Schaltelements (132) mit einem Ende des achten Widerstandes (125) verbunden wird und das andere Ende des achten Widerstandes (125) mit dem Stromabflussanschluss des zweiten Leistungshalbleiter-Schaltelements (132) verbunden wird.

4. Resonanzwandler nach Anspruch 3, wobei das Leistungshalbleiter-Schaltelement (200) aus einem Bipolartransistor mit isoliertem Gate, einem MOSFET und einem bipolaren Sperrschichttransistor ausgewählt ist.

5. Resonanzwandler nach Anspruch 3, wobei ein Wert eines ersten Kondensators (111) der Gate-Ansteuerschaltung (100) und ein Wert des ersten Widerstandes (121) festgelegt werden, um eine Totzeit der Gate-Ansteuerschaltung (100) einzustellen.

6. Resonanzwandler nach Anspruch 3, wobei ein Wert eines ersten Kondensators (111) der Gate-Ansteuerschaltung (100) des ersten Schaltzweigs (A) so ausgelegt ist, dass er kleiner ist als ein Wert eines ersten Kondensators der Gate-Ansteuerschaltung des zweiten Schaltzweigs, und ein Wert eines ersten Widerstandes (121) der Gate-Ansteuerschaltung (100) des ersten Schaltzweigs (A) so ausgelegt ist, dass er kleiner ist als ein Wert eines ersten Widerstandes der Gate-Ansteuerschaltung des zweiten Schaltzweigs, so dass ein Betriebsfrequenzbereich des Leistungshalbleiter-Schaltelements (200) der Gate-Ansteuerschaltung (100) des ersten Schaltzweigs (A) breiter ist als ein Betriebsfrequenzbereich des Leistungshalbleiter-Schaltelements der Gate-Ansteuerschaltung des zweiten Schaltzweigs.

7. Resonanzwandler nach Anspruch 1, der ferner eine Steuereinheit umfasst, die ein Gate-Ansteuersignal an die Gate-Ansteuerschaltung (100) anlegt.

8. Resonanzwandler nach Anspruch 7, wobei die Steuereinheit umfasst:

eine Schaltfrequenzerzeugungseinheit (810), die eine Schaltfrequenz erzeugt, die für einen Betrieb des ersten (A) und des zweiten Schaltzweigs erforderlich ist; und
eine Betriebsbestimmungseinheit (820), die das Ein/Aus-Schalten der Schaltfrequenzerzeugungseinheit (810) stabil steuert.

9. Resonanzwandler nach Anspruch 8, wobei:

die Schaltfrequenzerzeugungseinheit (810) so ausgelegt ist, dass sie eine Spannungssteuereinheit (811), eine Stromsteuereinheit (812), einen Schaltfrequenzmodulator (814), eine Diodeneinheit (813), die eine an den Schaltfrequenzmodulator (814) angelegte Spannung bestimmt, einen Schaltfrequenzphasenschieber (815) und ein UND-Gatter (816) umfasst;
die Spannungssteuereinheit (811) einen erfassten Ausgangsgleichspannungswert mit einem Zielreferenzspannungswert vergleicht, und wenn der erfasste Wert kleiner ist als der Referenzspannungswert, eine Spannung ausgibt, die zu einer Differenz zwischen dem erfassten Wert und dem Referenzspannungswert proportional ist;
die Stromsteuereinheit (812) einen erfassten Ausgangsgleichstromwert mit einem Zielreferenzstromwert vergleicht, und wenn der erfasste Wert kleiner ist als der Referenzstromwert, eine Spannung ausgibt, die zu einer Differenz zwischen dem erfassten Wert und dem Referenzstromwert proportional ist;
eine Diodeneinheit (813) Ausgangsspannungswerte von der Spannungssteuereinheit (811) und der Stromsteuereinheit (812) vergleicht und eine kleinere der Ausgangsspannungen an den Schaltfrequenzmodulator (814) anlegt;
der Schaltfrequenzmodulator (814) eine Schaltfrequenz im Verhältnis zu einer Amplitude eines Signals ausgibt, das von der Spannungssteuereinheit (811) oder der Stromsteuereinheit (812) durch die Diodeneinheit (813) angelegt wird;
der Schaltfrequenzphasenschieber (815) die Schaltfrequenz vom Schaltfrequenzmodulator

(814) empfängt, um eine Frequenz zu erzeugen, die von der Schaltfrequenz gemäß einer Anzahl des ersten (A) und der zweiten Schaltzweige phasenverschoben ist; und

das UND-Gatter (816) gemäß der Anzahl des ersten (A) und der zweiten Schaltzweige mehrfach vorgesehen ist und die Frequenz vom Schaltfrequenzphasenschieber (815) durch einen Anschluss durch jedes UND-Gatter (816) empfängt, um die Verantwortung für jeden Schaltzweig zu übernehmen.

10. Resonanzwandler nach Anspruch 8, wobei:

die Betriebsbestimmungseinheit (820) einen SR-Zwischenspeicher (823), einen Komparator (821) und ein ODER-Gatter (822) umfasst;

der Komparator (821) einen Wert, der von einem Ausgangsanschluss erfasst wird, mit einem vorbestimmten Referenzwert vergleicht, und wenn der erfasste Wert größer ist als der vorbestimmte Referenzwert, ein hohes Ausgangssignal ausgibt;

das ODER-Gatter (822) ein auf eine Schutzschaltung bezogenes Signal mit einem Wert empfängt, der aus dem Komparator (821) ausgegeben wird, und das auf die Schutzschaltung bezogene Signal an einen R-Anschluss des SR-Zwischenspeichers (823) für die Ausschaltsteuerung einer Leistungsversorgung ausgibt; und

der SR-Zwischenspeicher (823) eine Ausgabe eines Q-Anschlusses unter Verwendung des in den R-Anschluss eingegebenen Signals und eines Leistungsanlegesignals, das an einen S-Anschluss angelegt wird, bestimmt und die Ausgabe des Q-Anschlusses in die Schaltfrequenzerzeugungseinheit (810) eingibt.

Revendications

1. Convertisseur résonant pour convertir un courant continu (CC) en un autre courant continu (CC) avec un niveau souhaité, où lorsqu'une faible charge est connectée, seule une unique branche de commutation est actionnée pour prendre en charge la faible charge,

le convertisseur résonant comprenant une première branche de commutation (A) ayant une extrémité connectée à une borne positive (+) d'une source de puissance CC (Vcd) et l'autre extrémité connectée à une borne négative (-) de la source de puissance CC (Vcd),

la première branche de commutation (A) étant actionnée en tant qu'onduleur monophasé en demi-pont à une première fréquence de commutation sous une condition de faible charge et étant actionnée conjointement avec une ou plusieurs secondes branches de commutation à une seconde fréquence de commutation inférieure à la première fréquence de commutation sous une condition de charge nominale ou une condition de charge élevée ;

les une ou plusieurs secondes branches de commutation ayant une extrémité connectée à la borne positive (+) de la source de puissance CC (Vcd) et l'autre extrémité étant connectée à la borne négative (-) de la source de puissance CC (Vcd) et étant actionnée à la seconde fréquence de commutation sous une condition de charge nominale ;

dans lequel les première et seconde branches de commutation comprennent chacune deux unités de commutation connectées en série, et chaque unité de commutation comprend :

- un élément à semi-conducteur de commutation de puissance (200) ;
- une diode (300) comprenant une cathode connectée à une borne d'entrée de courant de l'élément à semi-conducteur de commutation de puissance (200) et une anode connectée à une borne de sortie de courant de l'élément à semi-conducteur de commutation de puissance (200) ;
- un condensateur amortisseur (400) connecté en parallèle à la diode ; et
- un circuit de pilotage de grille (100) appliquant un signal de commutation à une borne pour une commande de marche/arrêt de l'élément à semi-conducteur de commutation de puissance (200),

et dans lequel une valeur du condensateur amortisseur (400) pour empêcher une augmentation rapide de tension de la première branche de commutation (A) est conçue pour être inférieure à une valeur du condensateur amortisseur (400) des une ou plusieurs secondes branches de commutation de sorte qu'une détection de tension nulle du circuit de pilotage de grille (100) de la première branche de commutation (A) soit plus rapide qu'une détection de tension nulle du circuit de pilotage de grille de la seconde branche de commutation

2. Convertisseur résonant selon la revendication 1, dans lequel l'élément à semi-conducteur de commutation de puissance (200) est sélectionné à partir d'un transistor bipolaire à grille isolée, d'un transistor à effet de champ à semi-conducteur d'oxyde de métal, et d'un transistor à jonction bipolaire.

3. Convertisseur résonant selon la revendication 1, dans lequel :

le circuit de pilotage de grille (100) est configuré pour comprendre un premier élément à semi-conducteur de commutation de puissance

(131), un second élément à semi-conducteur de commutation de puissance (132), des première à troisième diodes (141-143), et des première à huitième résistances (121-126), et un condensateur (111) ;
pour distinguer un trajet de charge et un trajet de décharge d'un courant appliqué à la borne pour la commande de marche/arrêt de l'élément à semi-conducteur de commutation de puissance (200) de l'unité de commutation,
un signal de pilotage de grille est entré dans la borne de sortie de courant du premier élément à semi-conducteur de commutation de puissance (131), et une extrémité de la sixième résistance (123) est connectée à la borne de sortie de courant du premier élément à semi-conducteur de commutation de puissance (131) ;
la borne de sortie de courant du premier élément à semi-conducteur de commutation de puissance (131) est connectée à une extrémité du condensateur (111), à une extrémité de la quatrième résistance (124), à une extrémité de la deuxième résistance, et à la borne de sortie de courant de l'élément à semi-conducteur de commutation de puissance (200) de l'unité de commutation ;
l'autre extrémité du condensateur (111) est connectée à une extrémité de la première résistance (121), à une extrémité de la cinquième résistance (122), à une cathode de la première diode (141), et à une borne pour une commande de marche/arrêt du premier élément à semi-conducteur de commutation de puissance (131) ;
l'autre extrémité de la première résistance (121) est connectée à une extrémité de la deuxième résistance ;
une anode de la première diode (141) est connectée à une extrémité de la troisième résistance (126) ;
l'autre extrémité de la troisième résistance (126) est connectée à l'autre extrémité de la première résistance (121) ;
l'autre extrémité de la cinquième résistance (122) est connectée à une anode de la deuxième diode (142), et une cathode de la deuxième diode (142) est connectée à la borne d'entrée de courant de l'élément à semi-conducteur de commutation de puissance (200) de l'unité de commutation ;
l'autre extrémité de la sixième résistance (123) est connectée à une anode de la troisième diode (143) ;
une cathode de la troisième diode (143) est connectée à la borne pour la commande de marche/arrêt de l'élément à semi-conducteur de commutation de puissance (200) de l'unité de commutation, à une extrémité de la septième résistance, et à une borne de sortie de courant du second élément à semi-conducteur de commutation de puissance (132) ;
l'autre extrémité de la septième résistance est connectée à l'autre extrémité de la quatrième résistance (124) et à une borne pour une commande de marche/arrêt du second élément à semi-conducteur de commutation de puissance (132) ; et
la borne de sortie de courant du second élément à semi-conducteur de commutation de puissance (132) est connectée à une extrémité de la huitième résistance (125), et l'autre extrémité de la huitième résistance (125) est connectée à la borne de sortie de courant du second élément à semi-conducteur de commutation de puissance (132).

4. Convertisseur résonant selon la revendication 3, dans lequel l'élément à semi-conducteur de commutation de puissance (200) est sélectionné à partir d'un transistor bipolaire à grille isolée, d'un transistor à effet de champ à semi-conducteur d'oxyde de métal, et d'un transistor à jonction bipolaire.

5. Convertisseur résonant selon la revendication 3, dans lequel une valeur d'un premier condensateur (111) du circuit de pilotage de grille (100) et une valeur de la première résistance (121) sont établies pour régler un temps mort du circuit de pilotage de grille (100).

6. Convertisseur résonant selon la revendication 3, dans lequel une valeur d'un premier condensateur (111) du circuit de pilotage de grille (100) de la première branche de commutation (A) est conçue pour être inférieure à une valeur d'un premier condensateur du circuit de pilotage de grille de la seconde branche de commutation, et une valeur d'une première résistance (121) du circuit de pilotage de grille (100) de la première branche de commutation (A) est conçue pour être inférieure à une valeur d'une première résistance du circuit de pilotage de grille de la seconde branche de commutation, de sorte qu'une plage de fréquence d'actionnement de l'élément à semi-conducteur de commutation de puissance (200) du circuit de pilotage de grille (100) de la première branche de commutation (A) soit plus large qu'une plage de fréquence d'actionnement de l'élément à semi-conducteur de commutation de puissance du circuit de pilotage de grille de la seconde branche de commutation.

7. Convertisseur résonant selon la revendication 1, comprenant en outre un dispositif de commande qui applique un signal de pilotage de grille au circuit de pilotage de grille (100).

8. Convertisseur résonant selon la revendication 7, dans lequel le dispositif de commande comprend :

une unité de génération de fréquence de commutation (810) générant une fréquence de commutation nécessaire pour un actionnement des première (A) et seconde branches de commutation ; et
une unité de détermination d'actionnement (820) commandant de manière stable la marche/l'arrêt de l'unité de génération de fréquence de commutation (810).

9. Convertisseur résonant selon la revendication 8, dans lequel :

l'unité de génération de fréquence de commutation (810) est configurée pour comprendre un dispositif de commande de tension (811), un dispositif de commande de courant (812), un modulateur de fréquence de commutation (814), une unité de diode (813) déterminant une tension appliquée au modulateur de fréquence de commutation (814), un déphaseur de fréquence de commutation (815), et une grille ET (816) ;
le dispositif de commande de tension (811) compare une valeur de tension CC de sortie détectée à une valeur de tension de référence cible, et lorsque la valeur détectée est inférieure à la valeur de tension de référence, délivre une tension proportionnelle à une différence entre la valeur détectée et la valeur de tension de référence ;
le dispositif de commande de courant (812) compare une valeur de courant CC de sortie détectée à une valeur de courant de référence cible, et lorsque la valeur détectée est inférieure à la valeur de courant de référence, délivre une tension proportionnelle à une différence entre la valeur détectée et la valeur de courant de référence ;
l'unité de diode (813) compare des valeurs de tension de sortie provenant du dispositif de commande de tension (811) et du dispositif de commande de courant (812), et applique celle la plus petite des tensions de sortie au modulateur de fréquence de commutation (814) ;
le modulateur de fréquence de commutation (814) délivre une fréquence de commutation proportionnellement à une amplitude d'un signal appliqué à partir du dispositif de commande de tension (811) ou du dispositif de commande de courant (812) à travers l'unité de diode (813) ;
le déphaseur de fréquence de commutation (815) reçoit la fréquence de commutation à partir du modulateur de fréquence de commutation (814) pour générer un déphasage de fréquence à partir de la fréquence de commutation selon un nombre des première (A) et seconde branches de commutation ; et
la grille ET (816) est fournie en pluralité selon le nombre des première (A) et seconde branches de commutation et reçoit la fréquence à partir du déphaseur de fréquence de commutation (815) à travers une borne par chaque grille ET (816) pour prendre en charge chaque branche de commutation.

10. Convertisseur résonant selon la revendication 8, dans lequel :

l'unité de détermination d'actionnement (820) comprend un verrou SR (823), un comparateur (821), et une grille OU (822) ;
le comparateur (821) compare une valeur détectée à partir d'une borne de sortie à une valeur de référence prédéterminée, et lorsque la valeur détectée est supérieure à la valeur de référence prédéterminée, délivre un signal de sortie élevé ;
la grille OU (822) reçoit un signal lié au circuit de protection comprenant une valeur délivrée à partir du comparateur (821) et délivre le signal lié au circuit de protection à une borne R du verrou SR (823) pour une commande d'arrêt d'une alimentation électrique ; et
le verrou SR (823) détermine une sortie d'une borne Q en utilisant le signal entré dans la borne R et un signal d'application de puissance appliqué à une borne S et entre la sortie de la borne Q dans l'unité de génération de fréquence de commutation (810).

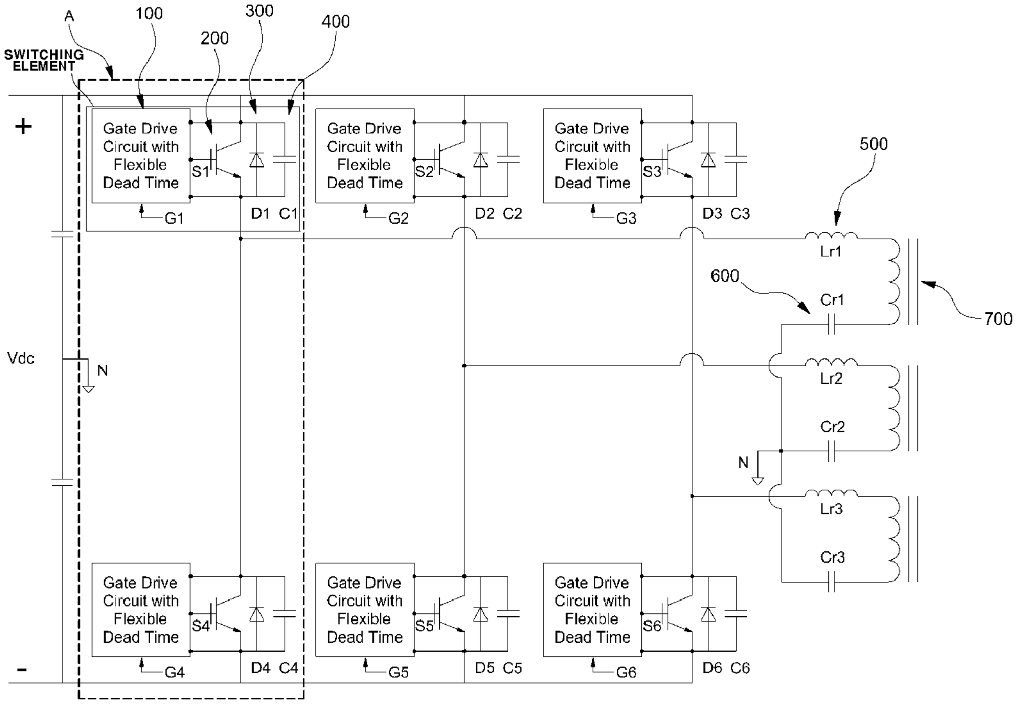

A
100
200
300
400
SWITCHING ELEMENT
+
Gate Drive Circuit with Flexible Dead Time
S1
G1
D1 C1
S2
G2
D2 C2
S3
G3
D3 C3
500
Lr1
600
Cr1
700
Vdc
N
Lr2
Cr2
N
Lr3
Cr3
S4
G4
D4 C4
S5
G5
D5 C5
S6
G6
D6 C6
-

FIG. 1

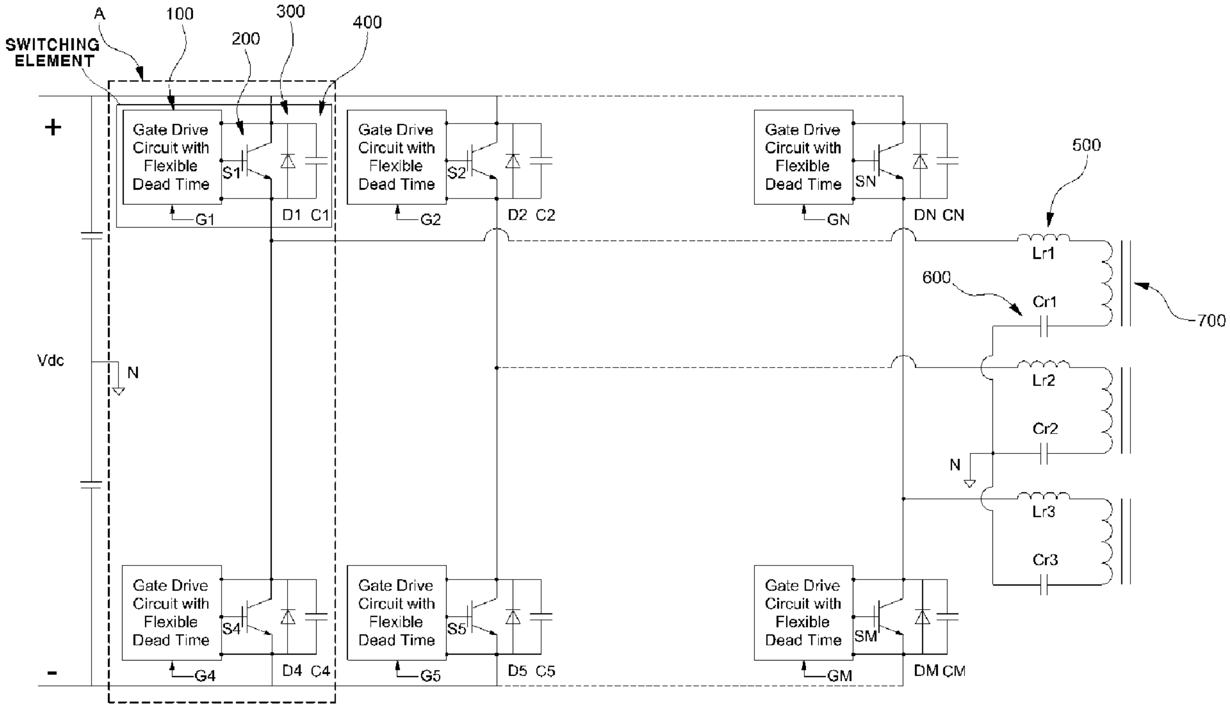

A
100
200
300
400
SWITCHING ELEMENT
+
Gate Drive Circuit with Flexible Dead Time
S1
G1
D1 C1
S2
G2
D2 C2
SN
GN
DN CN
500
Lr1
600
Cr1
700
Vdc
N
Lr2
Cr2
N
Lr3
Cr3
S4
G4
D4 C4
S5
G5
D5 C5
SM
GM
DM CM
-

FIG. 2

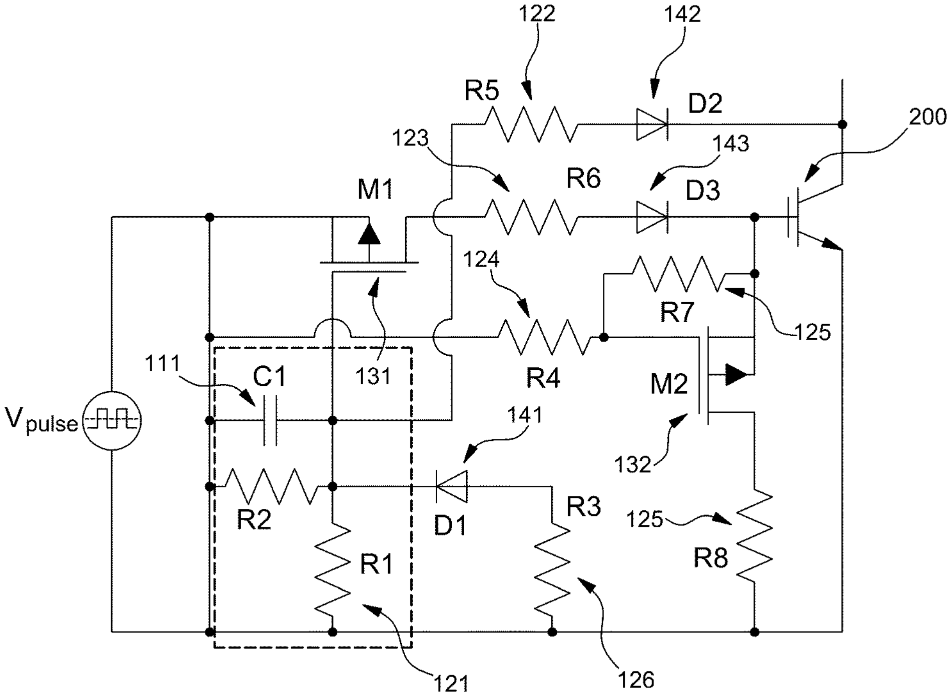

122
142
R5
D2
200
123
143
R6
D3
M1
124
R7
125
111
131
R4
C1
M2
Vpulse
141
132
R3
R2
D1
125
R8
R1
121
126

FIG.3

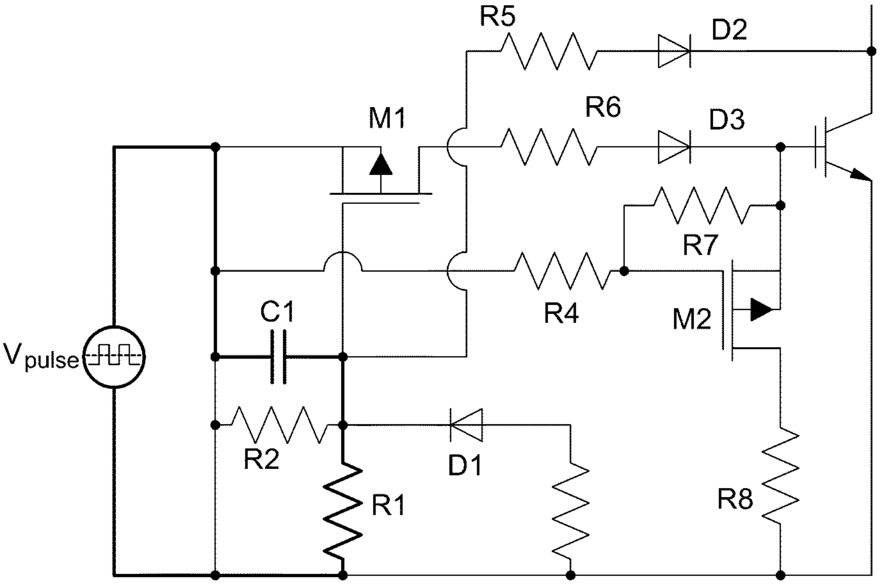

R5
D2
R6
D3
M1
R7
R4
C1
M2
Vpulse
R2
D1
R1
R8

FIG.4

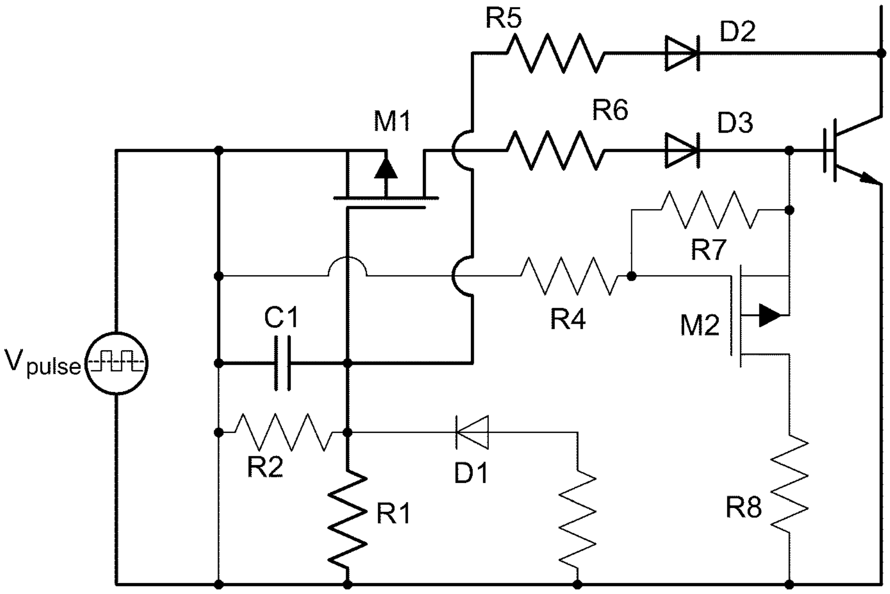

R5
D2
M1
R6
D3
R7
R4
C1
M2
V pulse
R2
D1
R1
R8

FIG.5

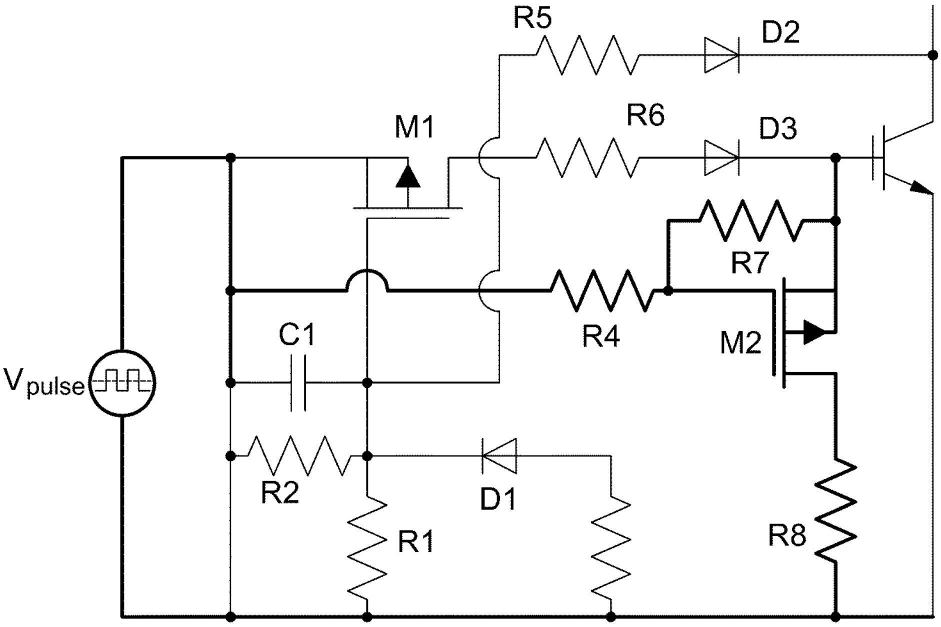

R5
D2
M1
R6
D3
R7
R4
C1
M2
V pulse
R2
D1
R1
R8

FIG.6

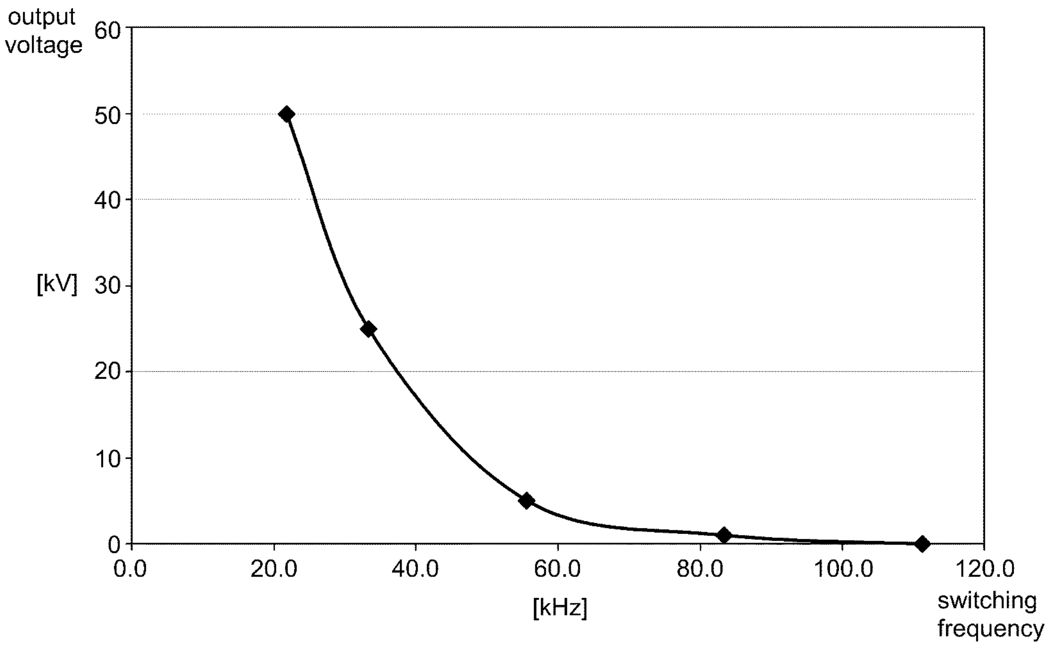

output voltage
[kV]
60
50
40
30
20
10
0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
[kHz]
switching frequency

FIG.7

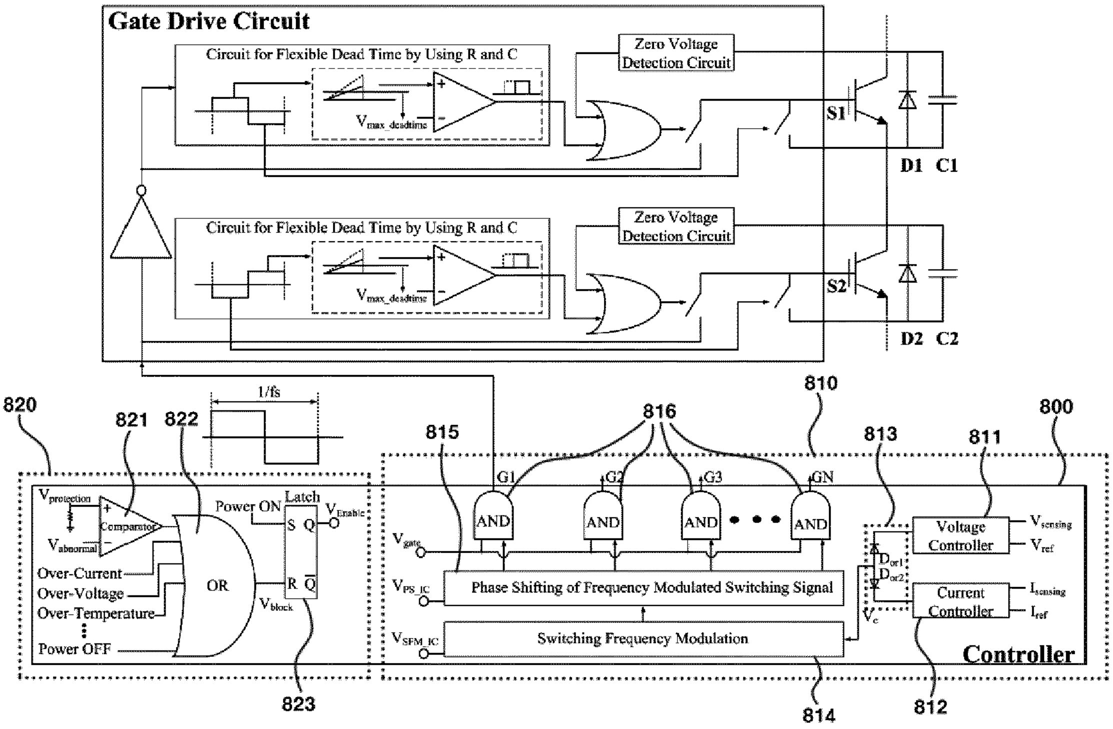
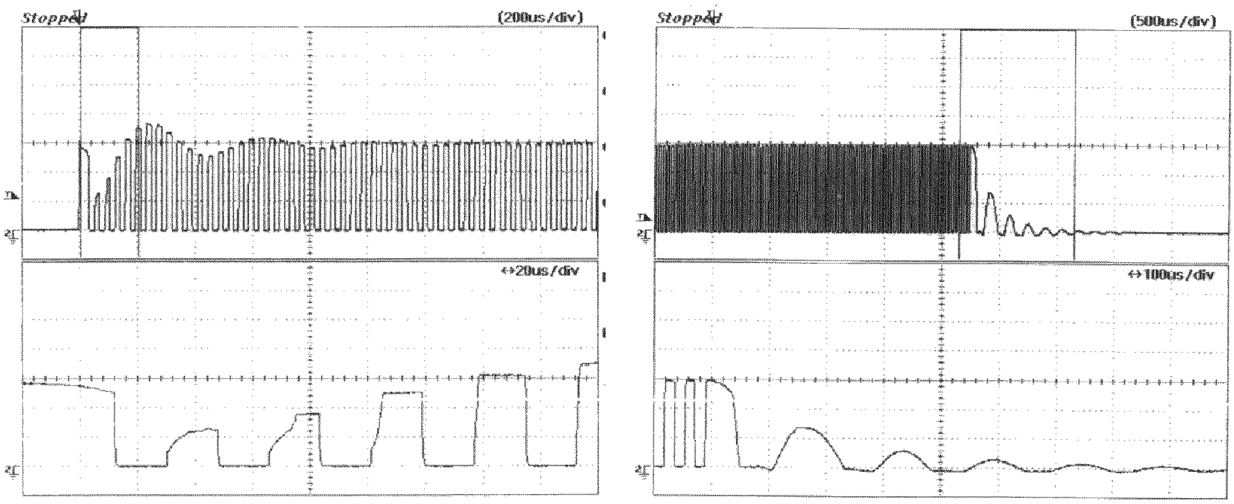

Gate Drive Circuit
Circuit for Flexible Dead Time by Using R and C
$V_{max\_deadtime}$
Zero Voltage Detection Circuit
S1
D1 C1
Circuit for Flexible Dead Time by Using R and C
$V_{max\_deadtime}$
Zero Voltage Detection Circuit
S2
D2 C2
1/fs
820
821
822
815
816
810
813
811
800
$V_{protection}$
$V_{abnormal}$
Comparator
Over-Current
Over-Voltage
Over-Temperature
Power OFF
OR
Power ON
Latch
S
Q
R
$\overline{Q}$
V_{Enable}
V_{block}
G1
G2
G3
GN
AND
AND
AND
AND
V_{gate}
V_{PS_IC}
V_{SFM_IC}
Phase Shifting of Frequency Modulated Switching Signal
Switching Frequency Modulation
D_{or1}
D_{or2}
V_c
Voltage Controller
Current Controller
$V_{sensing}$
V_{ref}
$I_{sensing}$
I_{ref}
Controller
823
814
812

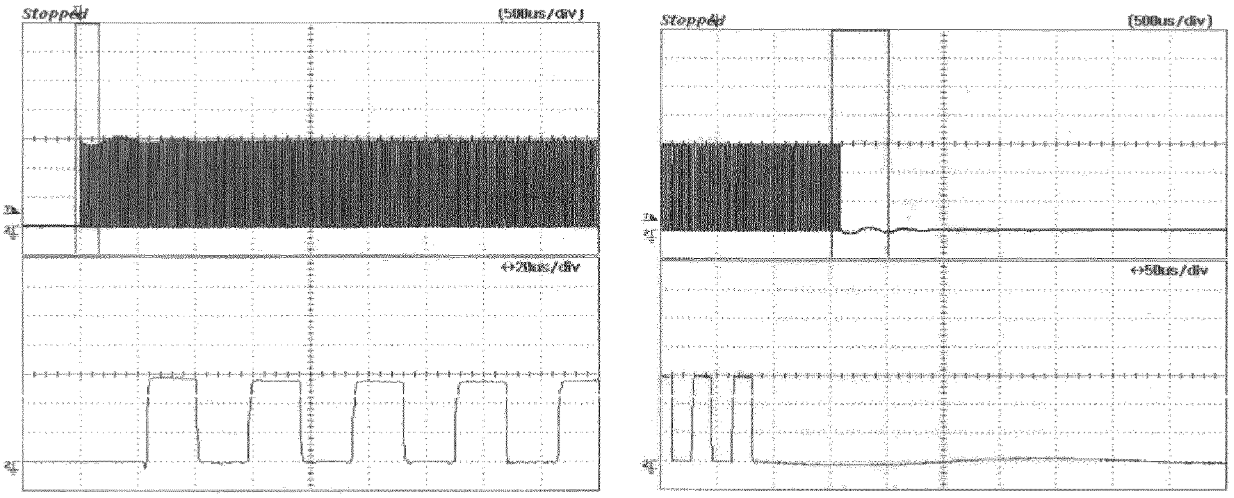
FIG.8



GATE VOLTAGE WAVEFORM IN TRANSIENT STATE UPON TURNING-ON (5V/div)

GATE VOLTAGE WAVEFORM IN TRANSIENT STATE UPON TURNING-OFF (5V/div)

FIG.9



GATE VOLTAGE WAVEFORM IN TRANSIENT STATE UPON TURNING-ON (5V/div)

GATE VOLTAGE WAVEFORM IN TRANSIENT STATE UPON TURNING-OFF (5V/div)

FIG.10

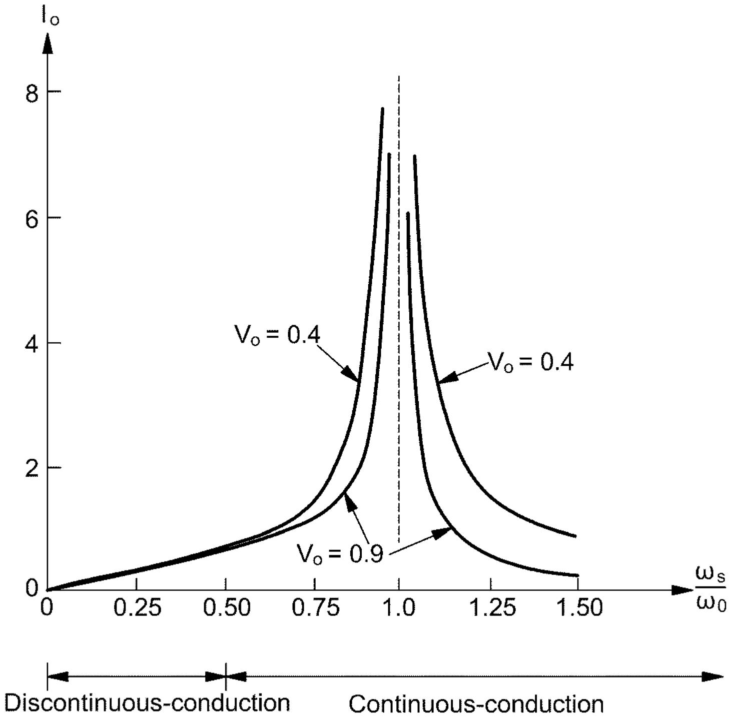

Io
8
6
4
2
0
Vo = 0.4
Vo = 0.4
Vo = 0.9
0
0.25
0.50
0.75
1.0
1.25
1.50
ωs/ω0
Discontinuous-conduction
Continuous-conduction

FIG.11

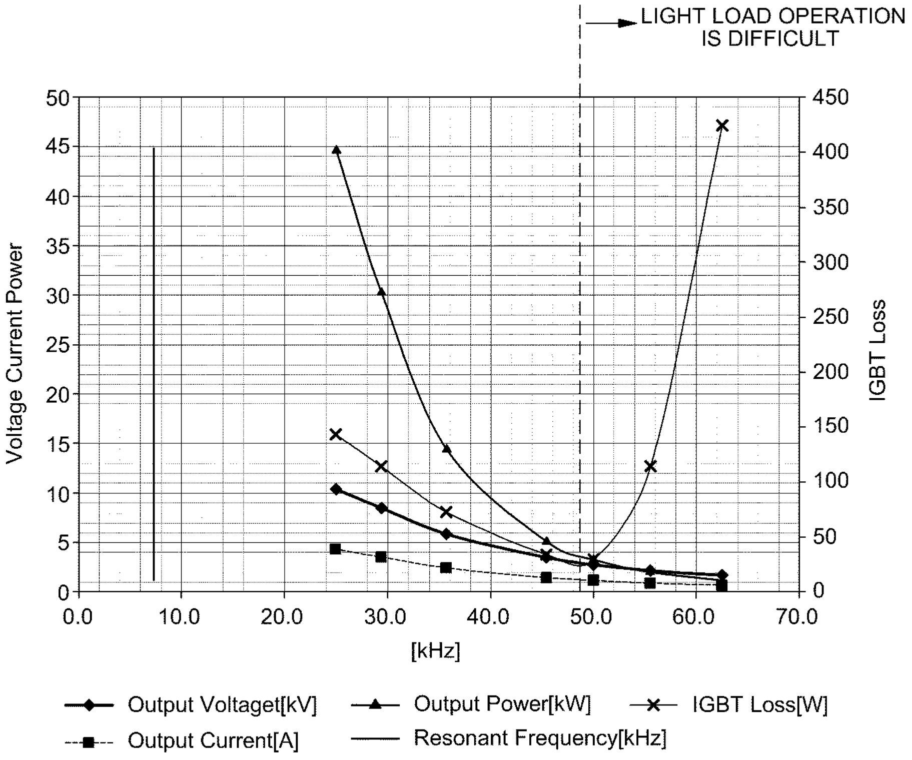

LIGHT LOAD OPERATION IS DIFFICULT
Voltage Current Power
50
45
40
35
30
25
20
15
10
5
0
450
400
350
300
250
200
150
100
50
0
IGBT Loss
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
[kHz]
Output Voltaget[kV]
Output Power[kW]
IGBT Loss[W]
Output Current[A]
Resonant Frequency[kHz]

FIG.12

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 2011254528 A **[0009]**
- DE 4337504 A1 **[0010]**

Non-patent literature cited in the description

- Paralleling of LLC resonant converters using frequency controlled current balancing. POWER ELECTRONICS SPECIALISTS CONFERENCE, 2008. PESC 2008. IEEE, 15 June 2008, 1080-1085 **[0011]**