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POWER SUPPLY DEVICE AND SWITCH DIAGNOSIS METHOD

Abstract

A power supply device is configured to be connected between first and second DC power supplies. The power supply device includes a first switch having one end connected to the first DC power supply, a DC-DC converter including a first capacitor connected to another end of the first switch, and a controller configured to control the DC-DC converter and the first switch and detect a potential difference between the one and another ends of the first switch. The DC-DC converter is configured to perform at least one of: a first operation converting a voltage stored in the first capacitor to the second voltage and outputting the second voltage to the second DC power supply; or a second operation of converting the second voltage supplied and held by the second DC power supply to a third voltage, and outputting the third voltage to the first capacitor. The controller is configured to: detect the potential difference after instructing the first switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation; and determine that the first switch is normal when the potential difference detected is greater than a first reference potential difference.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to a power supply device configured to be connected between two DC power supplies, and to a diagnosis method for a switch in the power supply device.

BACKGROUND ART

[0002] A power supply device connected between two DC power supplies (first DC power supply and second DC power supply) so as to convert power, may include a DC-DC converter converting a voltage on an input side (i.e., first DC power supply) into a desired voltage and output (i.e., charge) the desired voltage to an output side (i.e., second DC power supply). In this type of power supply device, a switch to connect and disconnect a component on the input side from the DC-DC converter and a switch to connect and disconnect a component on the output side from the DC-DC converter are provided in order to protect these two components connected at both ends. In particular, a state whether the switch can be turned off (i.e., switch is normal) is determined by measuring a potential difference between both ends of the switch after the switch is turned off.

[0003] Such a conventional technology is disclosed in PTL 1.

CITATION LIST

Patent Literature

[0004] PTL 1: WO 2019/077958

SUMMARY OF INVENTION

[0005] In a conventional power supply device, a switch is turned off and then a potential difference between both ends of the switch is measured in order to diagnose a turned-off of the switch. In other words, it is determined that the turned-off performance of the switch is normal when the potential difference between both ends of the switch is greater than a reference potential difference, and the turned-off performance of the switch is not normal when the potential difference is not greater than the reference potential difference.

[0006] However, when a charge is accumulated inside a DC-DC converter (hereinafter also referred to as “internal charge), the potential difference between both ends of the switch may be small due to a voltage associated with accumulation of the internal charge although the switch is properly responding to an instruction of turning off and being turned off. As a result, a turned-off state of the switch may not be properly diagnosed.

[0007] a leak current from a resistor in the DC-DC converter or a decrease in the internal charge due to spontaneous discharge is used for properly diagnosing the turned-off state of the switch. In this method, however, it may take time to discharge the internal charge of the DC-DC converter, and a long standby time may be necessary for determining the turned-off state of the switch.

[0008] Furthermore, although a voltage on an input side or an output side is held by a capacitor and the switch is properly responding to the turning-off instruction and is turned off, the potential difference between both ends of the switch may be small when the voltage on the input side or the output side is equal to a ground potential and an internal voltage of the DC-DC converter is also equal to the ground potential. In this case, the turned-off performance of the switch may be hardly

diagnosed based on the potential difference between both ends of the switch.

[0009] In order to properly diagnose the turned-off state of the switch in the above cases, the turned-off state of the switch may be diagnosed by turning off the switch after increasing the voltage on the input side or the output side by the power supply device and then waiting for the leak current from the resistor in the DC-DC converter or a decrease in the internal charge by spontaneous discharge. However, this method may require a long time until the internal charge of the DC-DC converter is discharged. As a result, a long standby time may be necessary for determining the turned-off state of the switch before starting an operation of the power supply device.

[0010] An object of the present disclosure may provide a power supply device and a switch diagnosis method that are capable of diagnosing, in a short period of time, the turned-off performance of the switch provided between the input side or the output side and a DC-DC converter in the power supply device.

[0011] A power supply device according to one aspect of the present disclosure is configured to be connected between a first direct-current (DC) power supply and a second DC power supply. The first DC power supply is configured to supply and hold a first voltage. The second DC power supply is configured to supply and hold a second voltage. The power supply device includes a first switch having one end connected to the first DC power supply, a DC-DC converter including a first capacitor connected to another end of the first switch, and a controller configured to control the DC-DC converter and the first switch and detect a potential difference between the one end and the another end of the first switch. The DC-DC converter is configured to perform at least one of: a first operation converting a voltage stored in the first capacitor to the second voltage and outputting the second voltage to the second DC power supply; or a second operation of converting the second voltage supplied and held by the second DC power supply to a third voltage, and outputting the third voltage to the first capacitor. The controller is configured to: detect the potential difference after instructing the first switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation; and determine that the first switch is normal when the potential difference detected is greater than a first reference potential difference.

[0012] In a diagnosis method for the above-described power supply device according to one aspect of the present disclosure, a potential difference between the one end and the another end of the switch is detected after instructing the switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation. It is determining that the switch is normal when the potential difference detected is greater than a reference potential difference.

[0013] The present disclosure provides the power supply device and the switch diagnosis method that are capable of diagnosing, in a short period of time, the turned-off performance of the switch provided between the input side or the output side and the DC-DC converter in the power supply device.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. 1A illustrates a configuration of a power supply device according to an exemplary embodiment.

[0015] FIG. 1B is a flow chart illustrating a process of diagnosing a turned-off performance of a first switch in an operation of the power supply device according to the embodiment.

[0016] FIG. 1C is a flow chart illustrating a process of diagnosing turned-off performance of a second switch in the operation of the power supply device according to the embodiment.

[0017] FIG. 2 illustrates a configuration example of a power supply device according to Modification 1 of the embodiment.

[0018] FIG. 3 illustrates a configuration example of a power supply device according to Modification 2 of the embodiment.

[0019] FIG. 4 illustrates a configuration example of a power supply device according to Modification 3 of the embodiment.

[0020] FIG. 5 illustrates a configuration example of a power supply device according to Modification 4 of the embodiment.

[0021] FIG. 6 illustrates a configuration example of a power supply device according to Modification 5 of the embodiment.

[0022] FIG. 7 illustrates a circuit of a DC-DC converter according to Example 1 of the power supply device according to the embodiment.

[0023] FIG. 8 illustrates a circuit of a DC-DC converter according to Example 2 of the power supply device according to the embodiment.

[0024] FIG. 9 illustrates a circuit of a DC-DC converter according to Example 3 of the power supply device according to the embodiment.

DESCRIPTION OF EMBODIMENT

[0025] An exemplary embodiment of the present disclosure will be described below with reference to the drawings. The exemplary embodiment disclosed herein is illustrative and not restrictive.

[0026] Still more, detailed description more than necessary may be omitted in the exemplary embodiment described below. For example, detailed description of known items and duplicate description of substantially equivalent components may be omitted. This is to avoid unnecessary redundancy of the description for easier understanding of persons skilled in the art. Furthermore, "A and B are connected to each other" signifies that A is electrically connected to B and includes states in which A and B are indirectly connected to each other via other circuit components between A and B, in addition to a case where A and B are directly connected to each other.

[0027] FIG. 1A is a block diagram of power supply device 1 according to an exemplary embodiment. In the present embodiment, power supply device 1 is installed in vehicle 100. As illustrated in FIG. 1A, power supply device 1 according to the embodiment includes first direct-current (DC) power supply 2, second DC power supply 3, DC-DC converter 4, first switch 5, second switch 6, controller 7, first voltage detector 51, second voltage detector 52, third voltage detector 61, and fourth voltage detector 62. Controller 7 includes diagnosis unit 8.

[0028] For convenience of description, controller 7 includes diagnosis unit 8. However, controller 7 and diagnosis unit 8 may be separate components. Still more, first voltage detector 51, second voltage detector 52, third voltage detector 61, and fourth voltage detector 62 may be installed in diagnosis unit 8.

[0029] First DC power supply 2 is configured to output (i.e., supply and hold) a first voltage. For example, first DC power supply 2 is a battery. Second DC power supply 3 is configured to output (supply and hold) a second voltage. For example, second DC power supply 3 is an electric double-layer capacitor.

[0030] DC-DC converter 4 is connected between first DC power supply 2 and second DC power supply 3. DC-DC converter 4 includes first capacitor 91 configured to store the first voltage, second capacitor 92 configured to store the second voltage, current sensor 42 configured to measure current flowing in DC-DC converter 4, and power conversion circuit 41 configured to perform DC voltage conversion to step down the first voltage to the second voltage and DC voltage conversion to boost the second voltage to the first voltage.

[0031] DC-DC converter 4 step down the first voltage input from first DC power supply 2, and outputs the stepped-down voltage to second DC power supply 3. In addition, DC-DC converter 4 boosts the second voltage input from second DC power supply 3 and outputs the boosted voltage to first DC power supply 2. In accordance with the present embodiment, DC-DC converter 4 steps down the first voltage input from first DC power supply 2 so as to output the stepped-down voltage to second DC power supply 3, and boosts the second voltage input from second DC power supply 3

so as to output the boosted voltage to first DC power supply **2**. DC-DC converter **4** may boost the first voltage input from first DC power supply **2** so as to output the boosted increased voltage to second DC power supply **3**, and may step down the second voltage input from second DC power supply **3** so as to output the stepped-down voltage to first DC power supply **2**.

[0032] First switch **5** is connected between first DC power supply **2** and DC-DC converter **4** and is configured to connect and disconnect first DC power supply **2** from DC-DC converter **4**.

[0033] Second switch **6** is connected between second DC power supply **3** and DC-DC converter **4** and is configured to connect and disconnect between second DC power supply **3** and DC-DC converter **4**.

[0034] First switch **5** and second switch **6** are, for example, semiconductor switches, such as metal-oxide semiconductor field-effect transistors (MOSFETs) or contactors, such as electromagnetic relays.

[0035] First voltage detector **51**, second voltage detector **52**, third voltage detector **61**, and fourth voltage detector **62** are voltmeters, such as analog-to-digital (A-D) converters.

[0036] Controller **7** is configured to instruct a stepping-down control to step-down a voltage input to DC-DC converter **4** (i.e., step down the first voltage and output to the stepped-down voltage to second DC power supply **3**) or a boosting control to boost a voltage input to DC-DC converter **4** (i.e., boost the second voltage and output the boosted voltage to first DC power supply **2**). In addition, controller **7** is configured to instruct first switch **5** to connect and disconnect between first DC power supply **2** and DC-DC converter **4**. Controller **7** is further configured to instruct second switch **6** to connect and disconnect between second DC power supply **3** and DC-DC converter **4**.

[0037] Furthermore, controller **7** is configured to cause diagnosis unit **8** to measure a voltage at both ends or a potential difference between both ends of first switch **5**.

[0038] In order to diagnose a turned-off performance of first switch **5**, controller **7** instructs first switch **5** to be turned off and instructs second switch **6** to be turned on, and then, causes DC-DC converter **4** to perform a voltage conversion operation to discharge a charge stored in first capacitor **91** to second DC power supply. Accordingly, the embodiment provides power supply device **1** configured to diagnose the turn-off performance of first switch **5** in a short period of time.

[0039] Controller **7** and diagnosis unit **8** are configured with a memory storing a program, a processor that executes the program, an A/D converter, a timer, and the like.

[0040] An operation of power supply device **1** will be described below.

[0041] First, a normal voltage conversion operation will be described. The normal voltage conversion operation includes an operation of stepping down the first voltage of first DC power supply **2** to the second voltage and outputting the second voltage to second DC power supply **3**, and an operation of boosting the second voltage of second DC power supply **3** to the first voltage and outputting the first voltage to first DC power supply **2**.

[0042] For example, when vehicle **100** having power supply device **1** installed therein starts or vehicle **100** starts, controller **7** instructs first switch **5** to connect first DC power supply **2** to DC-DC converter **4**. In addition, controller **7** instructs second switch **6** to connect second DC power supply to DC-DC converter **4**.

[0043] First switch **5** connects first DC power supply **2** to DC-DC converter **4** in response to the instruction from controller **7**. Second switch **6** connects second DC power supply **3** to DC-DC converter **4** in response to the instruction from controller **7**.

[0044] The voltage input from first DC power supply **2** or second DC power supply **3** to DC-DC converter **4** is converted in response to a signal from controller **7** to DC-DC converter **4**. At this moment, first capacitor **91** is charged to the first voltage of first DC power supply **2**, and second capacitor **92** is charged to the second voltage of second DC power supply **3**.

[0045] A diagnosis operation performed on a function to cut off external connection after the above normal voltage conversion operation will be described below.

[0046] First, diagnosis of the turned-off performance of first switch **5** will be described.

[0047] FIG. 1B is a flow chart illustrating a process of diagnosing the turned-off performance of first switch 5 (i.e., a method of diagnosing the switch) in the operation of power supply device 1 according to the embodiment.

[0048] Controller 7 instructs first switch 5 to disconnect first DC power supply from DC-DC converter 4. Controller 7 instructs first switch 5 to be turned off to disconnect first DC power supply 2 from DC-DC converter 4 (step S10).

[0049] Furthermore, controller 7 instructs second switch 6 to connect second DC power supply 3 to DC-DC converter 4. Second switch 6 connects second DC power supply 3 to DC-DC converter 4 according to the instruction from controller 7 (step S11). Steps S10 and S11 may be performed in an opposite order to FIG. 1B or may be performed simultaneously to each other.

[0050] Next, controller 7 causes DC-DC converter 4 to operate to discharge the charge stored in first capacitor 91 of DC-DC converter 4 to second DC power supply 3 (step S12). More specifically, controller 7 instructs DC-DC converter 4 to perform the stepping-down operation and discharge the charge stored in first capacitor 91 of DC-DC converter 4 to second DC power supply 3.

[0051] Next, diagnosis unit 8 measures voltages at both ends, two points, of first switch 5 by first voltage detector 51 and second voltage detector 52, and calculates a potential difference between both ends of first switch 5 (step S13). When the potential difference between both ends of first switch 5 calculated by diagnosis unit 8 is not greater than a reference value ("No" at step S14), it is confirmed that first switch 5 does not disconnect first DC power supply 2 from DC-DC converter 4, and it is thus determined that first switch 5 is abnormal, i.e., is not normal (step S15). When the potential difference between both ends of first switch 5 calculated by diagnosis unit 8 is greater than the reference value ("Yes" at step S14), it can be confirmed that first switch 5 disconnects first DC power supply 2 from DC-DC converter 4, and it is thus determined that first switch 5 is normal (step S16). As a result, the normal operation of a turned-off function of first switch 5 is determined. Controller 7 outputs a determination signal according to a normal or abnormal determination result of first switch 5 to, for example, an electronic control unit (ECU) installed in vehicle 100. The ECU performs operations (e.g., display, control) according to the determination signal.

[0052] As described above, in accordance with the embodiment, when controller 7 instructs first switch 5 to disconnect first DC power supply 2 from DC-DC converter 4, controller 7 causes DC-DC converter 4 to discharge the charge stored in first capacitor 91 connected between first switch 5 and a ground in DC-DC converter 4. Therefore, when first switch 5 is turned off, the potential difference between both ends of first switch 5 is large compared with a case of not discharging the charge. As a result, diagnosis unit 8 readily and reliably diagnoses first switch 5.

[0053] When controller 7 instructs first switch 5 to disconnect first DC power supply 2 from DC-DC converter 4, the charge stored in first capacitor 91 remains. In other words, first switch 5 is simply turned off. When diagnosis unit 8 measures the potential difference between both ends of first switch 5 in this state, the potential difference between both ends of first switch 5 is smaller than that in power supply device 1 of the present disclosure due to the charge remaining in first capacitor 91 even when first switch 5 is properly turned off. Thus, diagnosis unit 8 cannot determine whether or not first switch 5 is properly turned off.

[0054] Still more, the charge in first capacitor 91 is spontaneously discharged as time passes due to a resistor connected in parallel to the capacitor or leak current from DC-DC converter 4. Therefore, the potential difference between both ends of first switch 5 is measured after a certain time passes, and then, it may be determined whether or not first switch 5 is properly turned off. However, in power supply device 1 of the present disclosure, the charge in first capacitor 91 is actively discharged in a short period of time by controller 7 instructing DC-DC converter 4 to perform a voltage conversion after controller 7 instructs first switch 5 disconnect first DC power supply 2 from DC-DC converter 4. This configuration allows the charge stored in first capacitor 91 to be discharged in a significantly shorter period than the spontaneous discharge of the charge. As a

result, it is determined, in a shorter period than the spontaneous discharge, whether or not first switch **5** is properly turned off.

[0055] Next, diagnosis of the turned-off performance of second switch **6** will be described.

[0056] FIG. **1C** is a flow chart illustrating a process of diagnosing the turned-off performance of second switch **6** (i.e., a method of diagnosing the switch) in an operation of power supply device **1** according to the embodiment.

[0057] Controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**. Controller **7** instructs second switch **6** to be turned off to instruct second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4** (step **S20**).

[0058] Furthermore, controller **7** instructs first switch **5** to connect first DC power supply **2** to DC-DC converter **4**. Controller instructs first switch **5** to be turned on to instruct first switch **5** to connect first DC power supply **2** to DC-DC converter **4** (step **S21**). Steps **S20** and **S21** may be performed in an opposite order to FIG. **1C** or may be performed simultaneously to each other.

[0059] Next, controller **7** causes DC-DC converter **4** to operate to discharge the charge stored in second capacitor **92** of DC-DC converter **4** to first DC power supply **2** (step **S22**). More specifically, controller **7** instructs DC-DC converter **4** to perform the boosting operation and to discharge the charge stored in second capacitor **92** of DC-DC converter **4** to first DC power supply **2**.

[0060] Next, diagnosis unit **8** measures a voltage at both ends, two points, of second switch **6** by third voltage detector **61** and fourth voltage detector **62**, and calculates a potential difference between both ends of second switch **6** (step **S23**). When the potential difference between both ends of second switch **6** calculated by diagnosis unit **8** is not greater than a reference value (“No” at step **S24**), it is confirmed that second switch **6** does not disconnect second DC power supply **3** from DC-DC converter **4**, and it is thus determined that second switch **6** is abnormal, i.e., is not normal (step **S25**). When the potential difference between both ends of second switch **6** measured by diagnosis unit **8** is greater than the reference value (“Yes” in step **S24**), it is confirmed that second switch **6** disconnects second DC power supply **3** from DC-DC converter **4**, and it is thus determined that second switch **6** is normal (step **S26**). When the potential difference between both ends of second switch **6** measured by diagnosis unit **8** is not greater than a reference value (“No” in step **S24**), it is confirmed that second switch **6** does not disconnect second DC power supply **3** from DC-DC converter **4**, and it is thus determined that second switch **6** is abnormal, i.e., is not normal (step **S26**). As a result, the normal operation of a turned-off function of second switch **6** is determined. Controller **7** outputs a determination signal according to a normal or abnormal determination result of second switch **6** to, for example, an electronic control unit (ECU) installed in vehicle **100**. The ECU performs an operation (e.g., display, control) according to the determination signal.

[0061] As described above, in accordance with the present embodiment, when controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**, controller **7** causes DC-DC converter **4** to discharge the charge stored in second capacitor **92** connected between second switch **6** and a ground in DC-DC converter **4**. Therefore, when second switch **6** is turned off, the potential difference between both ends of second switch **6** is large compared with a case of not discharging the charge. As a result, diagnosis unit **8** readily and reliably diagnoses second switch **6**.

[0062] When controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**, the charge stored in second capacitor **92** remains. In other words, second switch **6** is simply turned off. When diagnosis unit **8** measures the potential difference between both ends of second switch **6** in this state, the potential difference between both ends of second switch **6** is smaller than that of power supply device **1** of the present disclosure due to the charge remaining in second capacitor **92** even when second switch **6** is properly turned off. Thus, diagnosis unit **8** does not determine whether or not second switch **6** is properly turned off.

[0063] Still more, the charge stored in second capacitor **92** is spontaneously discharged as time passes due to a resistor connected in parallel or leak current from DC-DC converter **4**. Therefore, in the prior art also, the potential difference between both ends of second switch **6** is measured after a certain time passes, it is determined whether or not second switch **6** is properly turned off. However, in power supply device **1** of the present disclosure, the charge stored in second capacitor **92** is actively discharged in a short period by controller **7** instructing DC-DC converter **4** to perform the voltage conversion after controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**. Accordingly, the charge stored in second capacitor **92** is discharged in a significantly short time of time compared with spontaneous discharge of the charge. As a result, it is determined, in a short period of time compared with the prior art, whether or not second switch **6** is properly turned off.

[0064] The reference value for the potential difference between both ends of each of first switch **5** and second switch **6** is determined based on an element employed in first switch **5** and second switch **6** or a component turned-off characteristic.

[0065] First DC power supply **2** may be substituted by a capacitor. The first voltage does not necessarily be supplied from an active power supply. The capacitor may be charged by DC-DC converter **4**, and a voltage after being charged may be regarded as the first voltage. This configuration allows the power supply of vehicle **100** to be constituted only by second DC power supply **3**. As a result, a vehicle configuration advantageous in terms of cost, component layout, weight, and the like can be achieved.

[0066] Second DC power supply **3** may be substituted by a capacitor. The second voltage does not necessarily be supplied from an active power supply. The capacitor may be charged by DC-DC converter **4**, and a voltage after being charged may be regarded as the second voltage. This configuration allows the power supply of vehicle **100** to be configured only by first DC power supply **2**. As a result, a vehicle configuration advantageous in terms of cost, component layout, weight, and the like can be achieved.

[0067] As illustrated in a configuration example of power supply device **1a** according to Modification **1** of the present exemplary embodiment in FIG. **2**, fifth voltage detector **53** may be provided to directly measure the potential difference between both ends of first switch **5** instead of first voltage detector **51** and second voltage detector **52** shown in FIG. **1A**. Fifth voltage detector **53** is, for example, an A/D converter.

[0068] Similarly, as illustrated in FIG. **2**, sixth voltage detector **63** may be provided to directly measure the potential difference between both ends of second switch **6** instead of third voltage detector **61** and fourth voltage detector **62** shown in FIG. **1A**. Sixth voltage detector **63** is, for example, an A/D converter.

[0069] In accordance with the embodiment, in order to diagnose the turned-off performance of first switch **5**, DC-DC converter **4** may operate to control the voltage of first capacitor **91**. More specifically, controller **7** instructs first switch **5** to disconnect first DC power supply **2** from DC-DC converter **4**, and then, controller **7** instructs DC-DC converter **4** to perform the voltage conversion. Here, the voltage of first capacitor **91** is controlled based on the voltage of first capacitor **91** detected by second voltage detector **52** shown in FIG. **1A**, so that the voltage of first capacitor **91** can be controlled (i.e., set) to an arbitrary voltage.

[0070] When first switch **5** is turned on, first capacitor **91** is charged to close to the voltage of first DC power supply **2**, and then, first switch **5** is turned off in order to reduce a rush current flowing to first switch **5** at connection.

[0071] For this purpose, in order to determine a proper turned-off function of first switch **5**, when first switch **5** is turned on again after the charge of first capacitor **91** is completely discharged, first capacitor **91** is charged to the voltage of first DC power supply **2**.

[0072] In contrast, when the voltage of first capacitor **91** is controlled to the arbitrary voltage not zero, a charging time before turning on first switch **5** again may be shortened.

[0073] For example, in order to cause the voltage of first capacitor **91** to the arbitrary voltage not zero, first voltage detector **51** monitors the voltage to maintain a potential difference necessary for determining the proper turn-off function of first switch **5** with respect to the voltage of second voltage detector **52**. For example, the voltage of first capacitor **91** is controlled to be the voltage lower than the first voltage by a reference value for determination. This configuration minimizes the charge discharged from first capacitor **91** necessary for determining the turned-off function of first switch **5**. As a result, a turned-off function determination time and a charging time before connecting first switch **5** again is shortened.

[0074] Similarly, to diagnose the turned-off performance of second switch **6**, DC-DC converter **4** may operate to control the voltage of second capacitor **92**. More specifically, controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**, and then controller **7** instructs DC-DC converter **4** to perform the voltage conversion. Here, the voltage of second capacitor **92** is controlled based on the voltage of second capacitor **92** detected by third voltage detector **61**, so that the voltage of second capacitor **92** can be controlled (i.e., set) to an arbitrary voltage.

[0075] When second switch **6** is turned on, second capacitor **92** is charged to close to the voltage of second DC power supply **3**, and then second switch **6** is turned on in order to reduce a rush current flowing to second switch **6** at connection.

[0076] For this purpose, when second switch **6** is connected again after the charge of second capacitor **92** is completely discharged for determining the proper turned-off function of second switch **6**, second capacitor **92** is charged to the voltage of second DC power supply **3**.

[0077] In contrast, when the voltage of second capacitor **92** is controlled to be the arbitrary voltage not zero, a charging time before connecting second switch **6** again is shortened.

[0078] For example, in order to control the voltage of second capacitor **92** to the arbitrary voltage not zero, fourth voltage detector **62** monitors the voltage to maintain a potential difference necessary for determining the proper turned-off function of second switch **6** with respect to the voltage of third voltage detector **61**. For example, the voltage of second capacitor **92** is controlled to be the voltage lower than the second voltage by a reference value for determination. This configuration minimizes the charge discharged from second capacitor **92** necessary for determining the turned-off function of second switch **6**. As a result, a turned-off function determination time and a charging time before connecting second switch **6** again can be shortened.

[0079] Note that diagnosis unit **8** may detect current flowing in power conversion circuit **41** of DC-DC converter **4** by current sensor **42**. After controller **7** instructs first switch **5** to disconnect first DC power supply **2** from DC-DC converter **4** or after controller **7** instructs second switch **6** to disconnect second DC power supply **3** from DC-DC converter **4**, controller **7** instructs DC-DC converter **4** to perform the voltage conversion. Here, current of DC-DC converter **4** is controlled such that current detected by current sensor **42** becomes not greater than a predetermined current or conversion by DC-DC converter **4** is stopped when detecting the current not less than the predetermined current. This configuration prevents excess power supply or excess current flow to first DC power supply **2** or second DC power supply **3** even when the turned-off performance of first switch **5** or second switch **6** as a diagnosis target is lost.

[0080] As illustrated in a configuration example of power supply device **1b** according to Modification **2** of the embodiment shown in FIG. **3**, the turned-off performance of first switch **5** is diagnosed even when only first switch **5** is provided without second switch **6** in the exemplary embodiment, and DC-DC converter **4a** is configured only with first capacitor **91** and power conversion circuit **41**.

[0081] Similarly, as illustrated in a configuration example of power supply device **1c** according to Modification **3** of the embodiment shown in FIG. **4**, the turned-off performance of second switch **6** is diagnosed even when only second switch is provided without first switch **5** and DC-DC converter **4b** is configured only with second capacitor **92** and power conversion circuit **41**.

[0082] Still more, as illustrated in a configuration example of power supply device **1d** according to Modification **4** of the embodiment shown in FIG. **5**, the turned-off performance of first switch **5a** and second switch **6a** is diagnosed by employing the method similar to the above embodiment even when each of first switch **5a** and second switch **6a** is implemented by a single MOSFET.

[0083] Since first switch **5a** is implemented by a MOSFET having a body diode with a forward direction from DC-DC converter **4** to first DC power supply **2**, as illustrated, first switch **5a** has a function to cut off current flowing from first DC power supply **2** to DC-DC converter **4** but does not have a function to cut off current flowing from DC-DC converter **4** to first DC power supply **2**. The embodiment is also capable of diagnosing the turned-off function of first switch **5a** as configured above since the voltage of first capacitor **91** decreases after turning off first switch **5a** in diagnosis of the turned-off performance.

[0084] Similarly, since second switch **6a** is implemented by a MOSFET having a body diode with a forward direction from DC-DC converter **4** to second DC power supply **3**, as illustrated, second switch **6a** has a function to cut off current flowing from second DC power supply **3** to DC-DC converter **4** but does not have a function to cut off current flowing from DC-DC converter **4** to second DC power supply **3**. The embodiment is also capable of diagnosing the turned-off function of second switch **6a** as configured above since the voltage of second capacitor **92** decreases after turning off second switch **6a** in diagnosis of the turned-off performance.

[0085] FIG. **6** illustrates a configuration example of power supply device **1e** according to Modification **5** of the embodiment.

[0086] Power supply device **1e** includes first DC power supply **2**, second DC power supply **3**, DC-DC converter **4**, first switch **5b**, second switch **6b**, controller **7a**, first voltage detector **51**, second voltage detector **52**, third voltage detector **61**, and fourth voltage detector **62**. Controller **7a** includes diagnosis unit **8**. Components identical to those of the exemplary embodiment are denoted by the same reference numerals, and their description will be omitted. Points that differ from the above exemplary embodiment will be mainly described.

[0087] As illustrated in FIG. **6**, first switch **5b** includes two MOSFETs connected in series to each other. The MOSFETs have body diodes with forward directions opposite to each other, and have a function to cut off current in both directions. Similarly, second switch **6b**, as illustrated in FIG. **6**, includes two MOSFETs connected in series to each other. The MOSFETs have body diodes with forward directions opposite to each other, and have a function to cut off current in both directions.

[0088] Controller **7a** and DC-DC converter **4** of Modification **5** has the following function in addition to the function described in the embodiment.

[0089] In other words, in order to diagnose first switch **5b**, controller **7a** instructs first switch **5b** to be turned off, and then, DC-DC converter **4** boosts the voltage of second capacitor **92** to convert the voltage output to first capacitor **91**, thereby charging first capacitor **91**.

[0090] In order to diagnose second switch **6b**, controller **7a** instructs second switch **6b** to be turned off, and then, DC-DC converter **4** steps down the voltage of first capacitor **91** to convert the voltage output to second capacitor **92**, thereby charging second capacitor **92**.

[0091] Accordingly, Modification **5** provides power supply device **1e** configured to diagnose, in a short period of time, the turned-off performances of first switch **5b** that disconnects first DC power supply **2** from DC-DC converter **4** and second switch **6b** that disconnects second DC power supply **3** from DC-DC converter **4**.

[0092] Next, an entire operation of power supply device **1e** will be described.

[0093] The normal voltage conversion operation is the same as the exemplary embodiment.

[0094] An operation in which an external connection is cut off after the normal voltage conversion operation will be described.

[0095] Controller **7a** instructs first switch **5b** to disconnect first DC power supply **2** from DC-DC converter **4**. First switch **5b** disconnects first DC power supply **2** from DC-DC converter **4** in response to the instruction from controller **7a**. For example, controller **7a** further changes a target

of voltage detection and monitoring to first capacitor **91**, and detects and monitors the voltage of first capacitor **91**.

[0096] Next, controller **7a** causes DC-DC converter **4** to operate such that the voltage of first capacitor **91** of DC-DC converter is controlled to be a voltage higher than the voltage of first DC power supply **2**. More specifically, controller **7a** instructs DC-DC converter **4** to perform the boosting operation, and the voltage of second DC power supply **3** is boosted by DC-DC converter **4**, so that the voltage of first capacitor **91** is controlled to be the voltage higher than that of first DC power supply **2**. Here, a control target of power conversion is first capacitor **91**, and thus the voltage of first capacitor **91** is controlled to be an arbitrary voltage greater than zero by DC-DC converter **4**.

[0097] Next, diagnosis unit **8** measures a potential difference between both ends of first switch **5b**. When the potential difference between both ends of first switch **5b** measured by diagnosis unit **8** is not greater than a reference value, it is confirmed that first switch **5b** is unable to properly respond to the instruction from controller **7a** and does not disconnect first DC power supply **2** from DC-DC converter **4**. When the potential difference between both ends of first switch **5b** measured by diagnosis unit **8** is greater than the reference value, it is confirmed that first switch **5b** is able to properly respond to the instruction from controller **7a** and disconnects first DC power supply **2** from DC-DC converter **4**. It is thus determined whether or not first switch **5b** is properly disconnect first DC power supply **2** from DC-DC converter **4**.

[0098] First switch **5a** according to Modification **4** illustrated in FIG. **5** is implemented by a single MOSFET. Therefore, in general, first switch **5a** does not have cut off current flowing in the direction from DC-DC converter **4** to first DC power supply **2** by the body diode even when first switch **5a** is controlled to be turned off. Only current flowing in a direction from first DC power supply **2** to DC-DC converter **4** is cut off. In contrast, first switch **5b** according to Modification **5** illustrated in FIG. **6** has a cut-off performance cutting off the current flowing in the direction from DC-DC converter **4** to first DC power supply **2**. In this case, by the method in Modification **5** the cut-off performance with respect to the current flowing in the direction from DC-DC converter **4** to first DC power supply **2** is diagnosed.

[0099] The above description of the operation to cut off external connection refers to a case where controller **7a** instructs to first switch **5b** to disconnect first DC power supply **2** from DC-DC converter **4**. However, the same operation applies to a case where controller **7a** instructs second switch **6b** to disconnect second DC power supply **3** from DC-DC converter **4**.

[0100] That is, controller **7a** instructs second switch **6b** to disconnect second DC power supply **3** from DC-DC converter **4**. Second switch **6b** disconnects second DC power supply **3** from DC-DC converter **4** in response to the instruction from controller **7a**. For example, controller **7a** further changes a target of voltage detection and monitoring to second capacitor **92**, and detects and monitors the voltage of second capacitor **92**.

[0101] Next, controller **7a** causes DC-DC converter **4** to operate such that the voltage of second capacitor **92** of DC-DC converter **4** is controlled to be a voltage higher than the voltage of second DC power supply **3**. More specifically, controller **7a** instructs to DC-DC converter **4** to perform the stepping-down operation, and the voltage of first DC power supply **2** is stepped down by DC-DC converter **4**, so that the voltage of second capacitor **92** is controlled to be the voltage higher than that of second DC power supply **3**. Here, a control target of power conversion is second capacitor **92**, and thus the voltage of second capacitor **92** is controlled to be an arbitrary voltage greater than zero by existing DC-DC converter **4**.

[0102] Next, diagnosis unit **8** measures a potential difference between both ends of second switch **6b**. When the potential difference between both ends of second switch **6b** measured by diagnosis unit **8** is not greater than the reference value, it is confirmed that second switch **6b** is unable to properly respond to the instruction from controller **7a** and to unable to disconnect second DC power supply **3** from DC-DC converter **4**. When the potential difference between both ends of

second switch **6b** measured by diagnosis unit **8** is greater than the reference value, it is confirmed that second switch **6b** is able to properly respond to the instruction from controller **7a** and to disconnect second DC power supply **3** from DC-DC converter **4**. It is thus determined whether or not second switch **6b** properly disconnects second DC power supply **3** from DC-DC converter **4**. [0103] Second switch **6a** according to Modification **4** illustrated in FIG. **5** is implemented by a single MOSFET. Therefore, in general, second switch **6b** does not have the cut-off performance with respect to current flowing in the direction from DC-DC converter **4** to second DC power supply **3** due to the body diode even when second switch **6b** is controlled to be turned off. Only current flowing in the direction from second DC power supply **3** to DC-DC converter **4** is cut off. In contrast, second switch **6b** according to Modification **5** illustrated in FIG. **6** has the cut-off performance with respect to the current flowing in the direction from DC-DC converter **4** to second DC power supply **3**. In this case, by the method in Modification **5**, the cut-off performance with respect to the current flowing in the direction from DC-DC converter **4** to second DC power supply **3** is diagnosed.

Configuration of DC-DC Converter **4**

[0104] An internal circuit of DC-DC converter **4** in accordance with the embodiment will be described below, for example, and performs the following operation.

[0105] FIG. **7** illustrates a circuit of DC-DC converter **4c** according to Example 1 of DC-DC converter **4** of the embodiment. The entire configuration of power supply device **1** including DC-DC converter **4c** is illustrated in FIG. **7**.

[0106] DC-DC converter **4c** includes first switching element **411**, second switching element **412**, reactor **413**, current sensor **42**, first capacitor **91**, and second capacitor **92**.

[0107] As illustrated in FIG. **7**, first switching element **411** and reactor **413** are connected in series to each other at node **J4c** in a direction from first switch **5** to second switch **6** in DC-DC converter **4c**. Second switching element **412** has one end connected to node **J4c** of switching element **411** and reactor **413**, and another end connected to a ground.

[0108] First switching element **411** is an N-channel MOSFET, and has a body diode. The body diode has an anode connected to a source of first switching element **411** and a cathode connected to a drain of first switching element **411**. Second switching element **412** is an N-channel MOSFET, and has a body diode. The body diode has an anode connected to a source of second switching element **412** and a cathode connected to a drain of second switching element **412**.

[0109] An operation of DC-DC converter **4c** will be described below.

[0110] In power supply device **1f**, DC-DC converter **4c** performs the stepping-down operation when charging second DC power supply **3** from first DC power supply **2**.

[0111] First switching element **411** and second switching element **412** perform switching operations under control of controller **7**, and a DC voltage of first DC power supply **2** is stepped down to charge second DC power supply **3**. More specifically, as an example, first switching element **411** is turned on and second switching element **412** is turned off to flow current from first DC power supply **2** to second DC power supply **3** via first switching element **411** and reactor **413**. Accordingly, energy is stored in reactor **413**. Still more, first switching element **411** is turned off and second switching element **412** is turned on to discharge energy stored in reactor **413** and flow current from the ground to second DC power supply via second switching element **412** and reactor **413**. The above state of storing energy in reactor **413** and the above state of flowing current from the ground to second DC power supply **3** via second switching element **412** and reactor **413** are alternately repeated.

[0112] In the switching operation of first switching element **411** and second switching element **412**, controller **7** feeds back the voltage of second DC power supply **3** to controller **7** to determine an on-duty of a drive signal using, for example, pulse width modulation (PWM), so as to control an output from DC-DC converter **4c**.

[0113] However, controller **7** may determine the on-duty of the drive signal to first switching

element **411** and second switching element **412** according to a difference with a target current value based on a current value detected by current sensor **42**.

[0114] Still more, in power supply device **1f**, DC-DC converter **4c** performs the boosting operation when charging first DC power supply **2** from second DC power supply **3**.

[0115] First switching element **411** and second switching element **412** perform switching operations under control of controller **7**, and a DC voltage of second DC power supply **3** is boosted to charge first DC power supply **2**. More specifically, as an example, first switching element **411** is turned off and second switching element **412** is turned on to flow current from second DC power supply **3** to the ground via reactor **413** and second switching element **412**. Accordingly, energy is stored in reactor **413**. Still more, first switching element **411** is turned on and second switching element **412** is turned off to discharge energy stored in reactor **413** and flow current from second DC power supply **3** to first DC power supply **2** via reactor **413** and first switching element **411**. The above state of storing energy in reactor **413** and the above state of flowing current from second DC power supply **3** to first DC power supply **2** via reactor **413** and first switching element **411** are alternately repeated.

[0116] In the switching operations of first switching element **411** and second switching element **412**, controller **7** feeds back the voltage of first DC power supply **2** to controller **7** to determine an on-duty of a drive signal using, for example, pulse width modulation (PWM), so as to control an output from DC-DC converter **4c**.

[0117] However, controller **7** may determine the on-duty of the drive signal to first switching element **411** and second switching element **412** according to a difference of a current value detected by current sensor **42** from a target current value.

[0118] FIG. **8** illustrates a circuit of DC-DC converter **4d** according to Example 2 of DC-DC converter **4** of the embodiment. An entire configuration of power supply device **1g** including DC-DC converter **4d** is illustrated in FIG. **8**.

[0119] DC-DC converter **4d** includes first switching element **411**, second switching element **412**, reactor **413**, third switching element **414**, fourth switching element **415**, current sensor **42**, first capacitor **91**, and second capacitor **92**. DC-DC converter **4d** includes third switching element **414** and fourth switching element **415** added to DC-DC converter **4c** of Example 1. Points that differ from DC-DC converter **4c** according to Example 1 will be mainly described below.

[0120] As illustrated in FIG. **8**, first switching element **411**, reactor **413**, and third switching element **414** are connected in series to each other at node **J4d** in DC-DC converter **4d** in order in a direction from first switch **5** to second switch **6**. Fourth switching element **415** has one end connected to node **J4d** of third switching element **414** and reactor **413**, and has another end connected to the ground.

[0121] Third switching element **414** is an N-channel MOSFET, and has a body diode. The body diode has an anode connected to a source of third switching element **414** and a cathode connected to a drain of third switching element **414**. Fourth switching element **415** is an N-channel MOSFET, and has a body diode. The body diode has an anode connected to a source of fourth switching element **415** and a cathode connected to a drain of fourth switching element **415**.

[0122] An operation of DC-DC converter **4d** will be described below.

[0123] In power supply device **1g**, DC-DC converter **4d** is configured to perform the boosting operation in addition to the stepping-down operation in response to an instruction from controller **7** when charging second DC power supply **3** from first DC power supply **2**.

[0124] In order to perform the stepping-down operation, the operation similar to DC-DC converter **4c** according to Example 1 is performed while third switching element **414** is turned on and fourth switching element **415** is turned off.

[0125] On the other hand, in order to perform the boosting operation, third switching element **414** and fourth switching element **415** perform the switching operation under control of controller **7** while continuously turning on first switching element **411** and turning off second switching

element **412** so as to boost the DC voltage of first DC power supply **2** and charge second DC power supply **3**. More specifically, as an example, third switching element **414** is turned off and fourth switching element **415** is turned on while continuously turning on first switching element **411** and turning off second switching element **412**, so that current flows from first DC power supply **2** to the ground via first switching element **411**, reactor **413**, and fourth switching element **415**. As a result, energy is stored in reactor **413**. Still more, third switching element **413** is turned on and fourth switching element **415** is turned off while continuously turning on first switching element **411** and turn off second switching element **412**, so that current flows from first DC power supply **2** to second DC power supply **3** via first switching element **411**, reactor **413**, and third switching element **414** by discharging energy stored in reactor **413**. The above state of storing energy in reactor **413** and the above state of current flowing from first DC power supply **2** to second DC power supply **3** via first switching element **411**, reactor **413**, and third switching element **414** are alternately repeated.

[0126] In order to diagnose the turned-off performance of first switch **5** of power supply device **1g** according to Example 2, similar to the embodiment, controller **7** instructs first switch **5** to be turned off and instructs second switch **6** to be turned on, and then, DC-DC converter **4d** performs the voltage conversion operation so as to discharge the charge in first capacitor **91** to second DC power supply **3**. Accordingly, power supply device **1** diagnoses the turned-off performance of first switch **5** in a short period of time.

[0127] In the switching operations of third switching element **414** and fourth switching element **415**, controller **7** feeds back the voltage of second DC power supply **3** to controller **7** to determine an on-duty of a drive signal using, for example, pulse width modulation (PWM), so as to control an output from DC-DC converter **4d**.

[0128] However, controller **7** may determine the on-duty of the drive signal to third switching element **414** and fourth switching element **415** according to the difference of the current value detected by current sensor **42** from a target current value.

[0129] Still more, in order to charge from second DC power supply **3** to first DC power supply **2** of power supply device **1g**, DC-DC converter **4d** may perform the stepping-down operation in addition to the boosting operation in response to the instruction from controller **7**.

[0130] To perform the boosting operation, the operation similar to DC-DC converter **4c** according to Example 1 is performed while continuously turning on third switching element **414** and turning off fourth switching element **415**.

[0131] On the other hand, in order to perform the stepping-down operation, third switching element **414** and fourth switching element **415** performs the switching operation under control of controller **7** while continuously turning on first switching element **411** and turning off second switching element **412**, so as to step down DC voltage of second DC power supply **3** to charge first DC power supply **2**. More specifically, as an example, third switching element **414** is turned on and fourth switching element **415** is turned off while continuously turning on first switching element **411** and turning off second switching element **412**, so that current flows from second DC power supply **3** to first DC power supply **2** via third switching element **414**, reactor **413**, and first switching element **411**. As a result, energy is stored in reactor **413**. Still more, third switching element **414** is turned off and fourth switching element **415** is turned on while continuously turning on first switching element **411** and turning off second switching element **412**, so that current flows from the ground to first DC power supply **2** via fourth switching element **415**, reactor **413**, and first switching element **411** by discharging energy stored in reactor **413**. The above state of storing energy in reactor **413** and the above state of flowing current from the ground to first DC power supply **2** via fourth switching element **415**, reactor **413**, and first switching element **411** are alternately repeated.

[0132] In order to diagnose the turned-off performance of second switch **6** of power supply device **1g** according to Example 2, similar to the embodiment, controller **7** instructs second switch **6** to be turned off and instructs first switch **5** to be turned on, and then DC-DC converter **4d** performs the

voltage conversion operation so as to discharge the charge stored in second capacitor **92** to first DC power supply **2**. Accordingly, power supply device **1** diagnoses the turned-off performance of second switch **6** in a short period of time.

[0133] In the switching operation of third switching element **414** and fourth switching element **415**, controller **7** feeds back the voltage of first DC power supply **2** to controller **7** to determine an on-duty of a drive signal using, for example, pulse width modulation (PWM), so as to control an output from DC-DC converter **4d**.

[0134] However, controller **7** may determine the on-duty of the drive signal to third switching element **414** and fourth switching element **415** according to the difference of the current value detected by current sensor **42** from the target current value.

[0135] FIG. **9** illustrates a circuit of DC-DC converter **4e** according to Example 3 of the exemplary embodiment. An entire configuration of power supply device **1h** including DC-DC converter **4e** is illustrated in FIG. **9**.

[0136] DC-DC converter **4e** includes fifth switching element **416**, transformer **417**, diode **418**, current sensor **42**, first capacitor **91**, and second capacitor **92**.

[0137] As illustrated in FIG. **9**, a primary winding of transformer **417** and switching element **416** are connected in series to each other in an order in a direction from first switch **5** in DC-DC converter **4e**. Fifth switching element **416** is an N-channel MOSFET having a grounded source and a drain connected to the primary winding of transformer **417**, and has a body diode. The body diode has an anode connected to a source of fifth switching element **416** and a cathode connected to a drain of fifth switching element **416**.

[0138] A secondary winding of transformer **417** has one end grounded and another end connected to an anode of diode **418**. Diode **418** has a cathode connected to second switch **6**. An operation of DC-DC converter **4e** will be described below.

[0139] DC-DC converter **4e** charges second DC power supply **3** from first DC power supply **2**. To charge second DC power supply **3** from first DC power supply **2** of power supply device **1h**, DC-DC converter **4e** performs the boosting and stepping-down operations according to an instruction from controller **7**. The boosting operation or stepping-down operation is determined based on a winding ratio of transformer **17**, an on-duty of a control signal from controller **7** to, e.g., fifth switching element **416**.

[0140] In order to charge second DC power supply **3** from first DC power supply **2**, fifth switching element performs the switching operation under control of controller **7**, and the DC voltage of first DC power supply **2** is boosted or stepped down to charge second DC power supply **3**. More specifically, as an example, an alternating-current (AC) voltage is generated in the secondary winding of transformer **417** by intermittent current flowing to the primary winding of transformer **417** due to the switching of fifth switching element **416**. The AC voltage is converted to a DC voltage by half-wave rectification by diode **418** and smoothing by second capacitor **92**, and the DC voltage is output to second DC power supply **3**.

[0141] To diagnose the shutoff performance of first switch **5** in power supply device **1h** according to Example 3, similar to the exemplary embodiment, controller **7** issues the instruction to first switch **5** to shut off and the instruction to second switch **6** to connect, and then DC-DC converter **4e** performs the voltage conversion operation to discharge the charge of first capacitor **91** to second DC power supply **3**. Accordingly, power supply device **1** can diagnose the shutoff performance of first switch **5** in a short period of time.

[0142] In the switching operation of fifth switching element **416**, controller **7** feeds back the voltage of second DC power supply **3** to controller **7** to determine an on-duty of a drive signal using, for example, pulse width modulation (PWM), so as to control an output from DC-DC converter **4e**.

[0143] Controller **7** may determine the on-duty of the drive signal to fifth switching element **416** according to the difference of the current value detected by current sensor **42** from the target

current value.

[0144] As described above, power supply device **1** according to the embodiment, modifications, and examples is the power supply device configured to be connected between first DC power supply **2** and second DC power supply **3**. First DC power supply **2** is configured to supply and hold the first voltage. Second DC power supply **3** is configured to supply and hold the second voltage. The power supply device includes first switch **5** having one end connected to first DC power supply **2**, first capacitor **91** connected to another end of first switch **5**, DC-DC converter **4**, and controller **7**. DC-DC converter **4** is configured to perform at least one of: the first operation of converting the voltage stored in first capacitor **91** to the second voltage and outputting the second voltage to second DC power supply **3**; or the second operation of converting the second voltage supplied and held by second DC power supply **3** to the third voltage and outputting the third voltage to first capacitor **91**. Controller **7** is configured to control DC-DC converter **4** and first switch **5** and detect the potential difference between both ends of first switch **5**. Controller **7** is configured to instruct the first switch **5** to be turned off and cause DC-DC converter **4** to perform the first operation or the second operation, and then detects the potential difference. When the potential difference detected is greater than the first reference potential difference, controller **7** is configured to determine that first switch **5** is normal.

[0145] Since DC-DC converter **4** performs the first operation or the second operation after first switch **5** is turned off in the diagnosis of first switch **5**, the potential difference between both ends of first switch **5** increases in a short period, compared with the prior art, when the turned-off performance of first switch **5** is normal. Accordingly, the present disclosure provides the power supply device configured to diagnose, in a short period of time, the turned-off performance of the switch provided between the input side or the output side and the DC-DC converter included in the power supply device.

[0146] Here, DC-DC converter **4** may perform the stepping-down operation or the boosting operation as the first operation or the second operation. Accordingly, the power supply device performs a power conversion between first DC power supply **2** and second DC power supply **3** having various voltages.

[0147] DC-DC converter **4** may include current sensor **42** configured to detect current flowing in DC-DC converter **4**. DC-DC converter **4** may perform at least one of the first operation or the second operation under control based on the current detected by current sensor **42**.

[0148] For example, when the current detected by current sensor **42** is not less than a predetermined value, it is determined to be abnormal, and DC-DC converter **4** may stop the at least the first operation or the second operation.

[0149] DC-DC converter **4** may charge first capacitor **91** with arbitrary third voltage by the first operation or the second operation while first switch **5** is turned off. This configuration suppresses an excessively large potential difference between both ends of first switch **5** in the diagnosis of first switch **5**, and thus, reduces time necessary for recovering the voltage of first capacitor **91** at completing the diagnosis.

[0150] Controller **7** may step down the voltage of first capacitor **91** to be lower than the first voltage by causing DC-DC converter **4** to perform the first operation after first switch **5** is turned off. In the diagnosis of first switch **5**, the cut-off performance cutting off current flowing in a direction from a terminal connected to first DC power supply **2** to a terminal connected to first capacitor **91** is diagnosed in addition to the diagnosis of the turned-off performance of first switch **5** in a short period of time compared with the prior art.

[0151] Controller **7** may boost the voltage of first capacitor **91** to be larger than the first voltage by causing DC-DC converter **4** to perform the second operation after first switch **5** is turned off. In the diagnosis of first switch **5**, the cut-off performance to cut off current flowing in a direction from the terminal connected to first capacitor **91** to the terminal connected to first DC power supply **2** is diagnosed in addition to the diagnosis of the turned-off performance of first switch **5** in a short

period compared with the prior art.

[0152] Power supply device **1** may further include second switch **6** having one end connected to second DC power supply **3**. DC-DC converter **4** may further include second capacitor **92** connected to another end of second switch **6**. Controller **7** may be further configured to turn off second switch **6** and cause DC-DC converter **5** to perform the first operation or the second operation, and then detect a potential difference between both ends of second switch **6**. Controller **7** may determine that second switch **6** is normal when the potential difference detected is greater than the second reference potential difference.

[0153] As a result, second switch **6** is diagnosed similarly to first switch **5** in addition to the diagnosis of first switch **5**.

[0154] In a method of diagnosing a switch according to the exemplary embodiment, modifications, and examples, first switch **5** included in power supply device **1** and connected between first DC power supply **2** and second DC power supply **3**. First DC power supply **2** supplies and holds the first voltage. Second DC power supply **3** supplies and holds the second voltage. First switch **5** has one end connected to first DC power supply **2**. Power supply device **1** includes DC-DC converter **4** configured to perform at least one of: the first operation of converting the voltage stored in first capacitor **91** to the second voltage and outputting the second voltage to second DC power supply **3**; or the second operation of converting the second voltage supplied and held by second DC power supply **3** to the third voltage and outputting the third voltage to first capacitor **91**. In the diagnosis method, both ends of first switch **5** are disconnected from each other (step **S10**) and DC-DC converter **4** performs the first operation or the second operation (step **S12**), and then, the potential difference between both ends of first switch **5** is detected (step **S13**). When the detected potential difference is greater than the first reference potential difference (“No” at step **S14**), it is determined that first switch **5** is normal (step **S16**).

[0155] Since first switch **5** is turned off and then DC-DC converter **4** performs the first operation or the second operation in the diagnosis of first switch **5**, the potential difference between both ends of first switch **5** increases in a short period compared with the prior art when the turned-off performance of first switch **5** is normal. The present disclosure thus provides achieves the switch diagnosis method that diagnoses, in a short period of time, the turned-off performance of the switch provided between the input side or the output side and the DC-DC converter included in the power supply device.

[0156] The power supply device and the switch diagnosis method of the present disclosure are described above with reference to the exemplary embodiment, modifications, and examples. However, the present disclosure is not limited by these exemplary embodiment, modifications, and concrete examples. Various modifications made to the exemplary embodiment, modifications, and examples or other exemplary embodiments configured by combining a part of the components of the exemplary embodiment, modifications, or examples by those skilled in the art are all embraced in the scope of the present disclosure without departing from the gist of the present disclosure.

INDUSTRIAL APPLICABILITY

[0157] A power supply device according to the present disclosure is configured to be between two DC power supplies to perform a voltage conversion. More specifically, the power supply device diagnoses, in a short period, the turned-off performance of a switch provided between the input side or the output side and a DC-DC converter included in the power supply device, and is widely applicable to, for example, an on-vehicle power conversion device for performing power conversion between a battery and a capacitor.

REFERENCE MARKS IN THE DRAWINGS

[0158] **1**, **1a-1h** power supply device [0159] **2** first DC power supply [0160] **3** second DC power supply [0161] **4**, **4a-4e** DC-DC converter [0162] **41** power conversion circuit [0163] **411** first switching element [0164] **412** second switching element [0165] **413** reactor [0166] **414** third switching element [0167] **415** fourth switching element [0168] **416** fifth switching element [0169]

417 transformer [0170] **418** diode [0171] **42** current sensor [0172] **5, 5a, 5b** first switch [0173] **51** first voltage detector [0174] **52** second voltage detector [0175] **53** fifth voltage detector [0176] **6, 6a, 6b** second switch [0177] **61** third voltage detector [0178] **62** fourth voltage detector [0179] **63** sixth voltage detector [0180] **7, 7a** controller [0181] **8** diagnosis unit [0182] **91** first capacitor [0183] **92** second capacitor [0184] **100** vehicle

Claims

1. A power supply device configured to be connected between a first direct-current (DC) power supply and a second DC power supply, the first DC power supply being configured to supply and hold a first voltage, the second DC power supply being configured to supply and hold a second voltage, the power supply device comprising: a first switch having one end connected to the first DC power supply; a DC-DC converter including a first capacitor connected to another end of the first switch; and a controller configured to control the DC-DC converter and the first switch and detect a potential difference between the one end and the another end of the first switch, wherein the DC-DC converter is configured to perform at least one of: a first operation converting a voltage stored in the first capacitor to the second voltage and outputting the second voltage to the second DC power supply; or a second operation of converting the second voltage supplied and held by the second DC power supply to a third voltage, and outputting the third voltage to the first capacitor, and the controller is configured to: detect the potential difference after instructing the first switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation; and determine that the first switch is normal when the potential difference detected is greater than a first reference potential difference.
2. The power supply device of claim 1, wherein the controller is configured to determine that the first switch is abnormal when the potential difference detected is not greater than the first reference potential difference.
3. The power supply device of claim 1, wherein the DC-DC converter is configured to perform a stepping-down operation as the first operation or the second operation.
4. The power supply device of claim 1, wherein the DC-DC converter performs a boosting operation as the first operation or the second operation.
5. The power supply device of claim 1, wherein the DC-DC converter includes a current sensor configured to detect current flowing in the DC-DC converter.
6. The power supply device of claim 5, wherein the DC-DC converter is configured to perform the at least one of the first operation or the second operation under control based on the current detected by the current sensor.
7. The power supply device of claim 6, wherein the DC-DC converter is configured to stop the at least one of the first operation or the second operation when the current detected by the current sensor is greater than or equal to a predetermined current.
8. The power supply device of claim 1, wherein the DC-DC converter is configured to charge the first capacitor to the third voltage by the first operation or the second operation while the first switch is turned off, the third voltage being an arbitrary voltage.
9. The power supply device of claim 1, wherein the controller is configured to step down the voltage of the first capacitor to be smaller than the first voltage by causing the DC-DC converter to perform the first operation after instructing the first switch to be turned off.
10. The power supply device of claim 1, wherein the controller is configured to boost the voltage of the first capacitor to be larger than the first voltage by causing the DC-DC converter to perform the second operation after instructing the first switch to be turned off.
11. The power supply device of claim 1, further comprising a second switch having one end connected to the second DC power supply, wherein the DC-DC converter further includes a second capacitor connected to another end of the second switch, and the controller is configured to: detect

a potential difference between both ends of the second switch after instructing the second switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation, and determine that the second switch is normal when the potential difference detected is greater than a second reference potential difference.

12. A method of diagnosing a power supply device connected between a first DC power supply and a second DC power supply, the first DC power supply supplying holding a first voltage, the second DC power supply supplying and holding a second voltage, the diagnosis method comprising: providing the power supply device including a switch having one end connected to the first DC power supply, and a DC-DC converter including a first capacitor connected to another end of the switch, the DC-DC converter being configured to perform at least one of: a first operation of converting a voltage stored in the first capacitor to the second voltage and outputting the second voltage to the second DC power supply; or a second operation of converting the second voltage supplied and held by the second DC power supply to a third voltage and outputting the third voltage to the first capacitor; detecting a potential difference between the one end and the another end of the switch after instructing the switch to be turned off and after causing the DC-DC converter to perform the first operation or the second operation; and determining that the switch is normal when the potential difference detected is greater than a reference potential difference.

13. The diagnosis method of claim 12, further comprising determining that the first switch is abnormal when the potential difference detected is not greater than the reference potential reference.
