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POWER SUPPLY DEVICE AND METHOD FOR CONTROLLING THE SAME

Abstract

A power supply device includes a first power source, a second power source, a switch circuit including a first switch to a third switch, a first reactor, a second reactor, and a control device configured to control the switch circuit and to alternately switch between a first state in which the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected to both ends of the second reactor and a second state in which the second power source is connected between the first node and the fourth node via the second reactor and the first power source is connected to both ends of the first reactor.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
[0001] Priority is claimed on Japanese Patent Application No. 2024-020382, filed Feb. 14, 2024, the content of which is incorporated herein by reference.
BACKGROUND OF THE INVENTION
Field of the Invention
[0002] The present invention relates to a power supply device and a method for controlling the same.
Description of Related Art
[0003] In recent years, in order to realize a low-carbon society, an increasing number of vehicles have been equipped with a running motor instead of an engine as a power generation source, or vehicles have been equipped with a running motor in addition to an engine. The following Patent Documents 1 and 2 disclose battery control systems for raising a temperature of a battery that supplies power to a running motor of such a vehicle. For example, the battery control system disclosed in the following Patent Document 1 includes a first battery and a second battery of which output characteristics differ according to the temperature, and when the temperature of the first battery is below a predetermined temperature, the temperature of the first battery is raised by preferentially using the second battery.
[0004] [Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2020-092509
[0005] [Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2023-527451
SUMMARY OF THE INVENTION
[0006] The battery control system disclosed in the above-described Patent Document 1 requires two batteries having different output characteristics according to the temperature, which leads to an increase in costs. In the battery control system disclosed in the above-described Patent Document 1, the temperature of the first battery is raised by arranging the second battery around the first battery, and thus it cannot be said that the batteries are effectively heated.
[0007] The aspects of the present invention have been made in consideration of the above circumstances, and an object thereof is to provide a power supply device and a method for controlling the same that can increase temperature of a plurality of power sources more efficiently than conventional methods without increasing costs by passing a high frequency current through them.
[0008] In order to solve the above problems and achieve the above object, the present invention employs the following aspects. [0009] (1): A power supply device according to one aspect of the present invention is a power supply device which includes a first power source connected between a first node and a second node, and a second power source connected between a third node and a fourth node, the power supply device supplying power to an electrical load connected between the first node and the fourth node, including a switch circuit including a first switch connected between

the first node and the third node, a second switch connected between the second node and the third node, and a third switch connected between the second node and the fourth node; a first reactor disposed between the first power source and the first node or the second node; a second reactor disposed between the second power source and the third node or the fourth node; and a control device configured to alternately switch between a first state in which the second switch and the third switch of the switch circuit are controlled to be in a closed state and the first switch is controlled to be in an open state, so that the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected to both ends of the second reactor and a second state in which the first switch and the second switch of the switch circuit are controlled to be in a closed state and the third switch is controlled to be in an open state, so that the second power source is connected between the first node and the fourth node via the second reactor and the first power source is connected to both ends of the first reactor. [0010] (2): in the aspect (1), when switching between the first state and the second state is performed, the control device temporarily may control the first switch and the third switch to the open state and the second switch to the closed state to set a third state in which the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected between the first node and the fourth node via the second reactor. [0011] (3): in the aspect (1) or (2), the power supply device may further include a voltage detection unit configured to detect a voltage of each of the first power source and the second power source, and the control device may perform balance control by alternately performing a first control in which the first switch is set to the closed state and the second switch and the third switch are set to the open state, and a second control in which the first switch, the second switch, and the third switch are set to the open state, when the voltage of the first power source is greater than the voltage of the second power source. [0012] (4): in the aspect (1) or (2), the power supply device may further include a voltage detection unit configured to detect a voltage of each of the first power source and the second power source, and the control device may perform balance control by alternately performing a third control in which the first switch and the second switch are set to the open state and the third switch is set to the closed state, and a second control in which the first switch, the second switch, and the third switch are set to the open state, when the voltage of the second power source is greater than the voltage of the first power source. [0013] (5): in the aspect (3) or (4), the control device may be configured to switch between a parallel state in which the first switch and the third switch are controlled to be in the closed state and the second switch is controlled to be in the open state, so that the first power source and the second power source are connected in parallel between the first node and the fourth node and a series state in which the first switch and the third switch are controlled to be in the open state and the second switch is controlled to be in the closed state, so that the first power source and the second power source are connected in series between the first node and the fourth node, and the balance control may be performed when a difference between a voltage of the first power source and a voltage of the second power source detected by the voltage detection unit is greater than or equal to a predetermined reference value and a transition to the parallel state is instructed. [0014] (6): A method for controlling a power supply device according to one aspect of the present invention is a method for controlling a power supply device which includes a first power source connected between a first node and a second node, and a second power source connected between a third node and a fourth node, and supplies power to an electrical load connected between the first node and the fourth node, wherein the power supply device includes a switch circuit including a first switch connected between the first node and the third node, a second switch connected between the second node and the third node, and a third switch connected between the second node and the fourth node, a first reactor disposed between the first power source and the first node or the second node, and a second reactor disposed between the second power source and the third node or the fourth node, and the method includes a step of alternately switching between a first state in which the second switch and the third switch of the

switch circuit are controlled to be in a closed state and the first switch is controlled to be in an open state, so that the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected to both ends of the second reactor and a second state in which the first switch and the second switch of the switch circuit are controlled to be in a closed state and the third switch is controlled to be in an open state, so that the second power source is connected between the first node and the fourth node via the second reactor and the first power source is connected to both ends of the first reactor.
[0015] According to the aspects (1) and (6), the open and closed states of the plurality of switches provided in the switch circuit are controlled to alternately switch between the first state and the second state. Thus, since a high frequency current can be applied to the first power source and the second power source, the first power source and the second power source can be heated more efficiently than before without increasing costs.
[0016] According to the aspect (2), when the first state and the second state are switched between, the first switch and the third switch are temporarily set to the open state and the second switch is temporarily set to the closed state, and thus it is possible to prevent the first switch and the third switch from being in the closed state at the same time.
[0017] According to aspects (3) and (4), since the balance control is performed in accordance with a magnitude relationship between the voltage of the first power source and the voltage of the second power source detected by the voltage detection unit, the voltage of the first power source and the voltage of the second power source can be made equal.
[0018] According to the aspect (5), when a difference between the voltage of the first power source and the voltage of the second power source detected by the voltage detection unit is greater than or equal to a predetermined reference value and a transition to a parallel state is instructed, the balance control is performed, and thus it is possible to curb a short-circuit current when transitioning to the parallel state.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0019] FIG. **1** is a circuit diagram showing a configuration of a main part of a power supply device according to an embodiment of the present invention.
[0020] FIG. **2** is a diagram showing current paths when the power supply device according to the embodiment of the present invention is operating in a series mode or parallel mode.
[0021] FIG. **3** is a diagram showing the current path when the power supply device of the embodiment of the present invention is operating in a heating mode.
[0022] FIG. **4** is a diagram showing a current change when the power supply device of the embodiment of the present invention is operating in the heating mode.
[0023] FIG. **5** is a diagram showing a relationship between an amplitude of a current that flows when the power supply device according to the embodiment of the present invention is operating in the heating mode and a ratio (T/Tf).
[0024] FIG. **6** is a diagram showing a current path when the power supply device according to the embodiment of the present invention is operating in a first voltage balance mode.
[0025] FIG. **7** is a diagram showing a current change when the power supply device according to the embodiment of the present invention is operating in the first voltage balance mode.
[0026] FIG. **8** is a diagram showing a current path when the power supply device according to the embodiment of the present invention is operating in a second voltage balance mode.
[0027] FIG. **9** is a diagram showing a current change when the power supply device according to the embodiment of the present invention is operating in the second voltage balance mode.
[0028] FIG. **10** is a flowchart showing a process when voltage balance control is performed in the

power supply device according to the embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] Hereinafter, embodiments of a power supply device and a method for controlling the same according to the present invention will be described with reference to the drawings.

Power Supply Device

[0030] FIG. **1** is a circuit diagram showing a configuration of a main part of a power supply device according to an embodiment of the present invention. As shown in FIG. **1**, the power supply device **1** according to this embodiment includes a first power source **11**, a second power source **12**, a switch circuit **13**, a first reactor **14**, a second reactor **15**, a capacitor **16**, a voltage detection unit **17**, a voltage detection unit **18**, and a control device **19**. Such a power supply device **1** supplies DC power to an electrical load connected via a contactor **20**, for example.

[0031] Here, examples of the electrical load to which DC power is supplied from the power supply device **1** include an inverter **21** that controls power running and regeneration of an electric motor M that generates a driving force for a vehicle, an auxiliary device **22** and an auxiliary voltage control unit (VCU) **23** provided in the vehicle, and an inlet **24** provided in the vehicle. In addition, for example, a three-phase brushless DC motor or the like can be used as the electric motor M. The auxiliary VCU **23** is a device that controls a voltage applied to the auxiliary device **22**.

[0032] The first power source **11** is a chargeable and dischargeable secondary cell (for example, a battery or the like). A positive terminal of the first power source **11** is connected to a first node N**1**, and a negative terminal is connected to a second node N**2**. The second power source **12** is a chargeable and dischargeable secondary cell (for example, a battery or the like). A positive terminal of the second power source **12** is connected to a third node N**3**, and a negative terminal is connected to a fourth node N**4**. The first power source **11** and the second power source **12** are the same power sources, and a voltage Vs**1** of the first power source **11** and a voltage Vs**2** of the second power source **12** are equal (or approximately equal). The voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** are voltages (for example, 400 V) suitable for operating the auxiliary device **22**.

[0033] In addition, one end of the above-described electrical load (the inverter **21**, the auxiliary VCU **23**, and the inlet **24**) is connected to the first node N**1** via the contactor **20**, and the other end is connected to the fourth node N**4** via the contactor **20**.

[0034] The switch circuit **13** includes three switching elements (a first switching element SW**1** to a third switching element SW**3** (a first switch to a third switch)) connected in series, and switches connection states of the first power source **11**, the second power source **12**, and the electrical load under the control of the control device **19**. The first switching element SW**1** is connected between the first node N**1** and the third node N**3**, the second switching element SW**2** is connected between the second node N**2** and the third node N**3**. The third switching element SW**3** is connected between the second node N**2** and the fourth node N**4**.

[0035] Here, for example, metal-oxide-semiconductor field-effect transistors (MOSFETs) can be used as the first switching element SW**1** to the third switching element SW**3**. When the MOSFETs are used as the first switching element SW**1** to the third switching element SW**3**, specific connection relationships are as follows. A drain of the first switching element SW**1** is connected to the first node N**1**, and a source thereof is connected to the third node N**3**. A drain of the second switching element SW**2** is connected to the third node N**3**, and a source thereof is connected to the second node N**2**. A drain of the third switching element SW**3** is connected to the second node N**2**, and a source thereof is connected to the fourth node N**4**. A diode is connected between the source and the drain of each of the first switching element SW**1** to the third switching element SW**3** in a forward direction from the source to the drain.

[0036] The switch circuit **13** is controlled to switch by, for example, a pulse width modulated (PWM) signal that is output from the control device **19** and input to gates of the first switching element SW**1** to the third switching element SW**3**. A specific method for controlling the switching

of the switch circuit **13** will be described below.
[0037] The first reactor **14** is disposed between the first power source **11** and the second node N**2**. More specifically, one end of the first reactor **14** is connected to the negative terminal of the first power source **11**, and the other end is connected to a connection point between the source of the second switching element SW**2** and the drain of the third switching element SW**3**. The second reactor **15** is disposed between the second power source **12** and the third node N**3**. More specifically, one end of the second reactor **15** is connected to the positive terminal of the second power source **12**, and the other end is connected to a connection point between the source of the first switching element SW**1** and the drain of the second switching element SW**2**.
[0038] The capacitor **16** is connected between the first node N**1** and the fourth node N**4**. Specifically, one electrode of the capacitor **16** is connected to the first node N**1**, and the other electrode is connected to the fourth node N**4**. The capacitor **16** is provided to smooth a current output from the power supply device **1**. The voltage detection unit **17** detects the voltage Vs**1** of the first power source **11**, and outputs a detection result thereof to the control device **19**. The voltage detection unit **18** detects the voltage Vs**2** of the second power source **12** and outputs a detection result thereof to the control device **19**.
[0039] The control device **19** includes, for example, a first control unit **19***a* and a second control unit **19***b*, and performs switching control of the switch circuit **13** and control of the electrical load (for example, drive control of the inverter **21**). The first control unit **19***a* performs the switching control of the switch circuit **13** to switch the connection states of the first power source **11**, the second power source **12**, and the electrical load.
[0040] Here, the power supply device **1** of the present embodiment has a parallel mode and a series mode as operation modes. The parallel mode is a mode in which the first power source **11** and the second power source **12** operate in a state in which they are connected in parallel to the electrical load (a parallel state). The series mode is a mode in which the first power source **11** and the second power source **12** operate in a state in which they are connected in series to the electrical load (a series state). The first control unit **19***a* controls the switch circuit **13** to switch between the parallel mode and the series mode.
[0041] The above-described operation modes include a heating mode and a voltage balance mode in addition to the above-described parallel mode and series mode. The heating mode is an operation mode in which the first power source **11** and the second power source **12** are heated by a chopper method. The voltage balance mode is an operation mode in which the voltage of the first power source **11** is equal to the voltage of the second power source **12**. When the voltage of the first power source **11** is different from the voltage of the second power source **12**, a short-circuit current flows from one of the first power source **11** and the second power source **12** to the other. In order to prevent this, the voltage balance mode is implemented. The operation modes and operation states of the power supply device **1** will be described in detail below.
[0042] The second control unit **19***b* controls the electrical load to which DC power is supplied from the power supply device **1**. For example, in a power running operation of the electric motor M, the second control unit **19***b* converts the DC power applied between the positive and negative terminals of the inverter **21** on the DC side into three-phase AC power, and sequentially commutates the supply of power to each phase of the electric motor M to supply each phase of the AC current. On the other hand, for example, in a regenerative operation of the electric motor M, the second control unit **19***b* converts generated AC power output from the electric motor M into DC power while synchronization on the basis of a rotation angle of the electric motor M is maintained.
Series Mode and Parallel Mode
[0043] FIG. **2** shows the current paths when the power supply device according to the embodiment of the present invention is operating in a series or parallel mode. In addition, the voltage detection units **17** and **18**, the control device **19**, and the electrical load are not shown in FIG. **2**. FIG. **2**(*a*) is a diagram showing a current path when it is operating in the series mode, and FIG. **2**(*b*) is a

diagram showing a current path when it is operating in the parallel mode.
[0044] As shown in FIG. **2**(*a*), in the series mode, the first control unit **19***a* of the control device **19** sets the second switching element SW**2** to a closed state (ON) and sets the first switching element SW**1** and the third switching element SW**3** to an open state (OFF). Thus, as shown in FIG. **2**(*a*), a current loop LP**1** that passes through the fourth node N**4**, the second power source **12**, the second reactor **15**, the second switching element SW**2**, the first reactor **14**, the first power source **11**, and the first node N**1** in this order is formed. That is, in the series mode, the first power source **11** and the second power source **12** are connected in series between the first node N**1** and the fourth node N**4**. During the regeneration, a current flows in a direction opposite to a direction of a current in the current loop LP**1** shown in FIG. **2**(*a*).
[0045] As shown in FIG. **2**(*b*), in the parallel mode, the first control unit **19***a* of the control device **19** sets the first switching element SW**1** and the third switching element SW**3** to the closed state (ON), and sets the second switching element SW**2** to the open state (OFF). Thus, as shown in FIG. **2**(*b*), a current loop LP**2** that passes through the fourth node N**4**, the third switching element SW**3**, the first reactor **14**, the first power source **11**, and the first node N**1** in this order, and a current loop LP**3** that passes through the fourth node N**4**, the second power source **12**, the second reactor **15**, the first switching element SW**1**, and the first node N**1** in this order are formed. That is, in the parallel mode, the first power source **11** and the second power source **12** are connected in parallel between the first node N**1** and the fourth node N**4**. During regeneration, a current flows in a direction opposite to a direction of a current in the current loops LP**2** and LP**3** shown in FIG. **2**(*b*).
Heating Mode
[0046] FIG. **3** is a diagram showing a current path when the power supply device according to the embodiment of the present invention is operating in the heating mode. As in FIG. **2**, illustration of the voltage detection units **17** and **18**, the control device **19**, and the electrical load is omitted in FIG. **3**. In the heating mode, the first control unit **19***a* of the control device **19** controls the switch circuit **13** to alternately switch between a first state shown in FIG. **3**(*a*) and a second state shown in FIG. **3**(*b*). A switching frequency between the first state and the second state is, for example, several tens to several hundreds of kHz.
[0047] Here, when the first state shown in FIG. **3**(*a*) is switched to the second state shown in FIG. **3**(*b*), the first control unit **19***a* first switches to the third state shown in FIG. **3**(*c*) and then switches to the second state shown in FIG. **3**(*b*). When the second state shown in FIG. **3**(*b*) is switched to the first state shown in FIG. **3**(*a*), the first control unit **19***a* first switches to the third state shown in FIG. **3**(*c*) and then switches to the first state shown in FIG. **3**(*a*).
[0048] Here, the above-described first state is a state in which the first power source **11** is connected between the first node N**1** and the fourth node N**4** via the first reactor **14**, and the second power source **12** is connected to both ends of the second reactor **15**. The above-described second state is a state in which the second power source **12** is connected between the first node N**1** and the fourth node N**4** via the second reactor **15**, and the first power source **11** is connected to both ends of the first reactor **14**. The above-described third state is a state in which the first power source **11** is connected between the first node N**1** and the fourth node N**4** via the first reactor **14**, and the second power source **12** is connected between the first node N**1** and the fourth node N**4** via the second reactor **15**.
[0049] As can be seen from FIGS. **3**(*a*) to **3**(*c*), in the heating mode, at least one of the first power source **11** and the second power source **12** is connected between the first node N**1** and the second node N**2**.
[0050] As shown in FIG. **3**(*a*), the first control unit **19***a* sets the above-described first state by setting the first switching element SW**1** to the open state (OFF) and setting the second switching element SW**2** and the third switching element SW**3** to the closed state (ON). In the first state, a current loop LP**11** that passes through the third switching element SW**3**, the first reactor **14**, the first power source **11**, and the capacitor **16** in this order is formed. A current loop LP**12** which

passes through the second power source **12**, the second reactor **15**, the second switching element SW**2**, and the third switching element SW**3** in this order is also formed. The current loop LP**11** is a current path in a state in which the first power source **11** is connected between the first node N**1** and the fourth node N**4** via the first reactor **14**. The current loop LP**12** is a current path in a state in which the second power source **12** is connected to both ends of the second reactor **15**.

[0051] As shown in FIG. **3**(*b*), the first control unit **19***a* sets the above-described second state by setting the first switching element SW**1** and the second switching element SW**2** to the closed state (ON) and setting the third switching element SW**3** to the open state (OFF). In the second state, a current loop LP**13** that passes through the first power source **11**, the first switching element SW**1**, the second switching element SW**2**, and the first reactor **14** in this order is formed. A current loop LP**14** which passes through the second power source **12**, the second reactor **15**, the first switching element SW**1**, and the capacitor **16** in this order is also formed. The current loop LP**13** is a current path in a state in which the first power source **11** is connected to both ends of the first reactor **14**. The current loop LP**14** is a current path in a state in which the second power source **12** is connected between the first node N**1** and the fourth node N**4** via the second reactor **15**.

[0052] As shown in FIG. **3**(*c*), the first control unit **19***a* sets the above-described third state by setting the first switching element SW**1** and the third switching element SW**3** to the open state (OFF) and setting the second switching element SW**2** to the closed state (ON). In the third state, the current loop LP**11** shown in FIG. **3**(*a*) and the current loop LP**14** shown in FIG. **3**(*b*) are formed. That is, in the third state, the first power source **11** and the second power source **12** are connected in parallel between the first node N**1** and the fourth node N**4**.

[0053] FIG. **4** is a diagram showing a current change when the power supply device according to the embodiment of the present invention is operating in the heating mode. In FIG. **4**, a period during which the first state shown in FIG. **3**(*a*) is set is defined as a period Ta**1**, and a period during which the second state shown in FIG. **3**B is set is defined as a period Tb**1**. When the first state shown in FIG. **3**(*a*) is switched to the second state shown in FIG. **3**(*b*), a period during which the third state shown in FIG. **3**(*c*) is temporarily set is defined as a period Ta**2**. When the second state shown in FIG. **3**(*b*) is switched to the first state shown in FIG. **3**(*a*), a period during which the third state shown in FIG. **3**(*c*) is temporarily set is defined as a period Tb**2**.

[0054] As shown in FIG. **4**, the first control unit **19***a* controls the first switching element SW**1** to the third switching element SW**3** of the switch circuit **13**, and switches between the states shown in FIGS. **3**(*a*) to **3**(*c*). Specifically, the state is switched in sequence, for example, such as the first state (the period Ta**1**) shown in FIG. **3**(*a*), the third state (the period Ta**2**) shown in FIG. **3**(*c*), the second state (the period Tb**1**) shown in FIG. **3**(*b*), the third state (the period Tb**2**) shown in FIG. **3**(*c*), the first state (the period Ta**1**) shown in FIG. **3**(*a*), . . .

[0055] In the period Ta**1** during which the first state shown in FIG. **3**(*a*) is set, the voltage Vs**1** of the first power source **11** is lower than an output voltage Vo of the power supply device **1**. Therefore, as shown in FIG. **4**, a current Is**1** flowing through the first power source **11** (a current flowing through the current loop LP**11** shown in FIG. **3**(*a*)) decreases. Specifically, when a reactance of the first reactor **14** is defined as L**1**, a rate of decrease of the current Is**1** is expressed as $dIs1/dt=(Vs1-Vo)/L1$. On the other hand, the voltage Vs**2** of the second power source **12** is higher than zero. Therefore, as shown in FIG. **4**, a current Is**2** flowing through the second power source **12** (a current flowing through the current loop LP**12** shown in FIG. **3**(*a*)) increases. Specifically, when a reactance of the second reactor **15** is defined as L**2**, a rate of increase of the current Is**2** is expressed as $dIs2/dt=Vs2/L2$.

[0056] In the period Tb**1** during which the second state shown in FIG. **3**(*b*) is set, the voltage Vs**1** of the first power source **11** is higher than zero. Therefore, as shown in FIG. **4**, the current Is**1** flowing through the first power source **11** (the current flowing through the current loop LP**13** shown in FIG. **3**(*b*)) increases. Specifically, the rate of increase of the current Is**1** is expressed as $dIs1/dt=Vs1/L1$. On the other hand, the voltage Vs**2** of the second power source **12** is lower than the output voltage Vo of the power supply device **1**. Therefore, as shown in FIG. **4**, the current Is**2** flowing through the second power source **12** (the current flowing through the current loop LP**14** shown in FIG. **3**(*b*)) decreases. Specifically, the rate of decrease of the current Is**2** is expressed as dIs**2**/dt=(Vs**2**−Vo)/L**2**.

[0057] In the periods Ta**2** and Tb**2** during which the third state shown in FIG. **3**(*c*) is set, the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** are both lower than the output voltage Vo of the power supply device **1**. Therefore, as shown in FIG. **4**, the current Is**1** flowing through the first power source **11** (the current flowing through the current loop LP**11** shown in FIG. **3**(*c*)) and the current Is**2** flowing through the second power source **12** (the current flowing through the current loop LP**14** shown in FIG. **3**(*c*)) decrease. Specifically, the rate of decrease of the current Is**1** is expressed as dIs**1**/dt=(Vs**1**−Vo)/L**1**, and the rate of decrease of the current Is**2** is expressed as dIs**2**/dt=(Vs**2**−Vo)/L**2**.

[0058] Here, the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** are defined as voltages Vs (Vs**1**=Vs**2**=Vs). The reactance L**1** of the first reactor **14** and the reactance L**2** of the second reactor **15** are defined as reactance L (L**1**=L**2**=L). Furthermore, a length Ta of the period Ta**1** during which the first state shown FIG. **3**(*a*) is set and a length Tb of the period Tb**1** during which the second state shown in FIG. **3**(*b*) is set are defined as lengths T (Ta=Tb=T). In addition, a ratio of the length T of the period Ta**1** or Tb**1** to a switching cycle Tf (refer to FIG. **4**) is set to 0.5 or less (T/Tf<0.5). Then, an amplitude ΔI_**1** of the current Is**1** flowing through the first power source **11** and an amplitude ΔI_**2** of the current Is**2** flowing through the second power source **12** are expressed as ΔI_**1**=ΔI **2**=Vs×T/L.

[0059] FIG. **5** is a diagram showing a relationship between the amplitude of the current that flows when the power supply device according to the embodiment of the present invention is operating in the heating mode and the ratio (T/Tf). With reference to FIG. **5**, when it is operating in the heating mode, an amplitude ΔI of the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** is proportional to the ratio (T/Tf). The amplitude ΔI is zero when the ratio (T/Tf) is zero, and is maximum when the ratio (T/Tf) is 0.5.

[0060] That is, as the ratios of the period Ta**2** and the period Tb**2** in the switching cycle Tf shown in FIG. **4** increase, the amplitude ΔI of the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** decreases. On the other hand, as the ratios of the periods Ta**2** and Tb**2** in the switching cycle Tf shown in FIG. **4** decrease, the amplitude ΔI of the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** increases. Therefore, in order to efficiently heat the first power source **11** and the second power source **12**, it is desirable to minimize the ratios of the period Ta**2** and the period Tb**2** in the switching cycle Tf shown in FIG. **4**.

[0061] By performing the switching shown in FIG. **4**, a boost operation of the first power source **11** and a boost operation of the second power source **12** are alternately performed in a state in which at least one of the first power source **11** and the second power source **12** is connected between the first node N**1** and the second node N**2**. Thus, since a high frequency current can be applied to the first power source **11** and the second power source **12**, the first power source and the second power source **12** can be heated more efficiently than before without increasing costs.

Voltage Balance Mode

First Voltage Balance Mode

[0062] FIG. **6** is a diagram showing a current path when the power supply device according to the embodiment of the present invention is operating in the first voltage balance mode. As in FIGS. **2** and **3**, illustration of the voltage detection units **17** and **18**, the control device **19**, and the electrical load is omitted in FIG. **6**. The first voltage balance mode is performed in a case in which the voltage Vs**1** of the first power source **11** is higher than the voltage Vs**2** of the second power source **12**, in order to make the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** equal to each other. In the first voltage balance mode, the first control unit **19***a* of the control device **19** controls the switch circuit **13** to alternately switch between an energy transfer state shown in FIG. **6**(*a*) and an energy recovery state shown in FIG. **6**(*b*).

[0063] Here, the energy transfer state shown in FIG. **6**(*a*) is a state in which the first power source **11** and the second power source **12** are connected in parallel. The energy recovery state shown in FIG. **6**(*b*) is a state in which the first power source **11** is connected via the capacitor **16**, the third switching element SW**3**, and the first reactor **14**, and the second power source **12** is connected to both ends of the second reactor **15**.

[0064] In the energy transfer state shown in FIG. **6**(*a*), electrical energy is transferred from the first power source **11** which has a higher voltage to the second power source **12**. However, when a voltage difference between the first power source **11** and the second power source **12** is large, a peak value Ip of the current flowing through the first power source **11** and the second power source **12** becomes larger. Therefore, when a magnitude of the current flowing through the first power source **11** and the second power source **12** reaches a certain value, a transition to the energy recovery state is made to stop the transfer of electrical energy from the first power source **11** which has a higher voltage to the second power source **12**.

[0065] In the energy recovery state shown in FIG. **6**(*b*), in order to reduce the increased peak value Ip of the current flowing through the first power source **11** and the second power source **12**, the electrical energy stored in the first reactor **14** and the second reactor **15** is recovered to the first power source **11** and the second power source **12**, respectively. The energy recovery state shown in FIG. **6** continues until the current IS**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** both become zero.

[0066] As shown in FIG. **6**(*a*), the first control unit **19***a* performs control (first control) to set the first switching element SW**1** to the closed state (ON) and the second switching element SW**2** and the third switching element SW**3** to an open state (OFF), thereby achieving the above-described energy transfer state. In the energy transfer state, a current loop LP**20** that passes through the first power source **11**, the first switching element SW**1**, the second reactor **15**, the second power source **12**, the third switching element SW**3**, and the first reactor **14** in this order is formed. The current loop LP**20** is a current path in a state in which the first power source **11** and the second power source **12** are connected in parallel.

[0067] As shown in FIG. **6**(*b*), the first control unit **19***a* performs control (second control) to set the first switching element SW**1** to the third switching element SW**3** to the open state (OFF), thereby achieving the above-described energy recovery state. In the energy recovery state, a current loop LP**21** that passes through the first power source **11**, the capacitor **16**, the third switching element SW**3**, and the first reactor **14** in this order is formed. A current loop LP**22** that passes through the second power source **12**, the third switching element SW**3**, the second switching element SW**2**, and the second reactor **15** in this order is also formed. The current loop LP**21** is a current path in a state in which the first power source **11** is connected to both ends of the first reactor **14**, and the current loop LP**22** is a current path in a state in which the second power source **12** is connected to both ends of the second reactor **15**.

[0068] FIG. **7** is a diagram showing a current change when the power supply device according to the embodiment of the present invention is operating in the first voltage balance mode. In FIG. **7**, a period during which the energy transfer state shown in FIG. **6**(*a*) is set is defined as a period Tc**1**, and a period during which the energy recovery state shown in FIG. **6**(*b*) is set is defined as a period Tc**2**. As shown in FIG. **7**, the first control unit **19***a* controls the first switching element SW**1** to the third switching element SW**3** of the switch circuit **13** to alternately switch between the energy transfer state shown in FIG. **6**(*a*) and the energy recovery state shown in FIG. **6**(*b*).

[0069] In the period Tc**1** during which the energy transfer state shown in FIG. **6**(*a*) is set, the current Is**1** flowing through the first power source **11** decreases, whereas the current Is**2** flowing through the second power source **12** increases. When a time from the start of the period Tc**1** is defined as t, the current Is**2** flowing through the second power source **12** is expressed as Is**2**=

(Vs**1**−Vs**2**)/(L**1**+L**2**)×t. When a length of the period Tc**1** is defined as t_c**1**, the peak value Ip of the current Is flowing through the first power source **11** and the second power source **12** is expressed as Ip=(Vs**1**−Vs**2**)/(L**1**+L**2**)×t_c**1**.

[0070] In the period Tc**2** in which the energy recovery state shown in FIG. **6**(*b*) is set, the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** both decrease to zero. A time required for the current Is**1** flowing through the first power source **11** to become zero is expressed as Vs**1**/L**1**×Ip. A time required for the current Is**2** flowing through the second power source **12** to become zero is expressed as Vs**2**/L**2**×Ip. Therefore, a time t_c**2** required for both the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** to become zero is a larger one of Vs**1**/L**1**×Ip and Vs**2**/L**2**×Ip.

[0071] When the switching shown in FIG. **7** is performed, as shown in the drawing, the voltage Vs**1** of the first power source **11** gradually decreases, whereas the voltage Vs**2** of the second power source **12** gradually increases. Then, by repeating the switching shown in FIG. **7**, the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** become equal to each other. In this way, by performing the control in the first voltage balance mode (first voltage balance control), the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** become equal to each other.

Second Voltage Balance Mode

[0072] FIG. **8** is a diagram showing a current path when the power supply device according to the embodiment of the present invention is operating in a second voltage balance mode. As in FIGS. **2**, **3** and **6**, illustration of the voltage detection units **17** and **18**, the control device **19** and the electrical load is omitted in FIG. **8**. The second voltage balance mode is performed in a case in which the voltage Vs**2** of the second power source **12** is higher than the voltage Vs**1** of the first power source **11**, in order to make the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** equal to each other. In the second voltage balance mode, the first control unit **19***a* of the control device **19** controls the switch circuit **13** to alternately switch between the energy transfer state shown in FIG. **8**(*a*) and the energy recovery state shown in FIG. **8**(*b*).

[0073] Here, the energy transfer state shown in FIG. **8**(*a*) is a state in which the first power source **11** and the second power source **12** are connected in parallel, as in the energy transfer state shown in FIG. **6**(*a*). The energy recovery state shown in FIG. **8**(*b*) is a state in which the first power source **11** is connected to both ends of the first reactor **14**, and the second power source **12** is connected via the second reactor **15**, the first switching element SW**1**, and the capacitor **16**.

[0074] In the energy transfer state shown in FIG. **8**(*a*), electrical energy is transferred from the second power source **12** which has a higher voltage to the first power source **11**. In the energy recovery state shown in FIG. **8**(*b*), in order to reduce the increased peak value Ip of the current flowing through the first power source **11** and the second power source **12**, the electrical energy stored in the first reactor **14** and the second reactor **15** is recovered to the first power source **11** and the second power source **12**, respectively.

[0075] As shown in FIG. **8**(*a*), the first control unit **19***a* performs control (third control) to set the first switching element SW**1** and the second switching element SW**2** to the open state (OFF) and the third switching element SW**3** to the closed state (ON), thereby achieving the above-described energy transfer state. In the energy transfer state, a current loop LP**30** that passes through the first power source **11**, the first reactor **14**, the third switching element SW**3**, the second power source **12**, the second reactor **15**, and the first switching element SW**1** in this order is formed. The current loop LP**30** is a current path in a state in which the first power source **11** and the second power source **12** are connected in parallel.

[0076] As shown in FIG. **8**(*b*), the first control unit **19***a* performs control (second control) to set the first switching element SW**1** to the third switching element SW**3** to the open state (OFF), thereby achieving the above-described energy recovery state. In the energy recovery state, a current loop

LP**31** that passes through the first power source **11**, the first reactor **14**, the second switching element SW**2**, and the first switching element SW**1** in this order is formed. A current loop LP**32** that passes through the second power source **12**, the second reactor **15**, the first switching element SW**1**, and the capacitor **16** in this order is also formed. The current loop LP**31** is a current path when the first power source **11** is connected to both ends of the first reactor **14**, and the current loop LP**32** is a current path when the second power source **12** is connected via the second reactor **15** and the capacitor **16**.

[0077] FIG. **9** is a diagram showing a current change when the power supply device according to the embodiment of the present invention is operating in the second voltage balance mode. In FIG. **9**, a period during which the energy transfer state shown in FIG. **8**(*a*) is set is defined as a period Td**1**, and a period during which the energy recovery state shown in FIG. **8**(*b*) is set is defined as a period Td**2**. As shown in FIG. **9**, the first control unit **19***a* controls the first switching element SW**1** to the third switching element SW**3** of the switch circuit **13** to alternately switch between the energy transfer state shown in FIG. **8**(*a*) and the energy recovery state shown in FIG. **8**(*b*).

[0078] In the period Td**1** during which the energy transfer state shown in FIG. **8**(*a*) is set, the current Is**2** flowing through the second power source **12** decreases, whereas the current Is**1** flowing through the first power source **11** increases. When a time from the start of the period Td**1** is defined as t, the current Is**1** flowing through the first power source **11** is expressed as Is**1**=(Vs**2**−Vs**1**)/(L**1**+L**2**)×t. When a length of the period Td**1** is defined as t_d**1**, the peak value Ip of the current Is flowing through the first power source **11** and the second power source **12** is expressed as Ip=(Vs**2**−Vs**1**)/(L**1**+L**2**)×t_d**1**.

[0079] In the period Td**2** during which the energy recovery state shown in FIG. **8**(*b*) is set, the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** both decrease to zero. A time t_d**2** required for the current Is**1** flowing through the first power source **11** and the current Is**2** flowing through the second power source **12** to both become 0 is larger one of Vs**1**/L**1**×Ip and Vs**2**/L**2**×Ip, similar to the time t_c**2** when it is operating in the first voltage balance mode.

[0080] When the switching shown in FIG. **9** is performed, as shown in the drawing, the voltage Vs**2** of the second power source **12** gradually decreases, whereas the voltage Vs**1** of the first power source **11** gradually increases. Then, by repeating the switching shown in FIG. **9**, the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** become equal to each other. In this way, by performing the control in the second voltage balance mode (second voltage balance control), the voltage Vs**1** of the first power source **11** and the voltage Vs**2** of the second power source **12** become equal to each other.

[0081] FIG. **10** is a flowchart showing a process when voltage balance control is performed in the power supply device according to the embodiment of the present invention. The flowchart shown in FIG. **10** is started, for example, every time a higher-level device (not shown) issues a transition instruction to a parallel connection to the control device **19** of the power supply device **1**. Such a transition instruction is issued, for example, when the vehicle is started.

[0082] When the process is started, the first control unit **19***a* of the control device **19** determines whether a difference (a voltage difference) between the voltage Vs**1** of the first power source **11** detected by the voltage detection unit **17** and the voltage Vs**2** of the second power source **12** detected by the voltage detection unit **18** is greater than or equal to a predetermined reference value (Step S**11**). When the first control unit **19***a* determines that the voltage difference is not greater than or equal to the reference value, the process shown in FIG. **10** ends. On the other hand, when the first control unit **19***a* determines that the voltage difference is greater than or equal to the reference value, it determines whether a status instructed from the higher-level device is a parallel state (Step S**12**).

[0083] When the first control unit **19***a* determines that the status instructed from the higher-level device is not the parallel state, the first control unit **19***a* ends the process shown in FIG. **10**. On the other hand, when the first control unit **19***a* determines that the status instructed from the higher-level device is the parallel state, the first control unit **19***a* determines whether a value obtained by subtracting the voltage Vs**2** of the second power source **12** from the voltage Vs**1** of the first power source **11** (hereinafter, referred to as a first potential difference) is smaller than a predetermined threshold value (Step S**13**).

[0084] When the first control unit **19***a* determines that the first potential difference is not smaller than the above-described threshold value (is greater than or equal to the above-described threshold value), it transitions to the first voltage balance mode described using FIGS. **6** and **7** and performs the first voltage balance control (Step S**14**). The first control unit **19***a* performs the first voltage balance control in Step S**14** until it determines in Step S**13** that the first potential difference is smaller than the threshold value. On the other hand, when the first control unit **19***a* determines that the first potential difference is smaller than the above-described threshold value, it determines whether a value obtained by subtracting the voltage Vs**1** of the first power source **11** from the voltage Vs**2** of the second power source **12** (hereinafter, referred to as a second potential difference) is smaller than a predetermined threshold value (Step S**15**).

[0085] When the first control unit **19***a* determines that the second potential difference is not smaller than the above-described threshold value (is greater than or equal to the above-described threshold value), it transitions to the second voltage balance mode described using FIGS. **8** and **9** and performs the second voltage balance control (Step S**16**). The first control unit **19***a* performs the second voltage balance control in Step S**16** until it determines in Step S**15** that the second potential difference is smaller than the threshold value. On the other hand, when the first control unit **19***a* determines that the second potential difference is smaller than the threshold value, it performs control to transition to the parallel state shown in FIG. **2**(*b*) (Step S**17**). When the above-described process is completed, the first control unit **19***a* ends the process shown in FIG. **10**.

[0086] As described above, the power supply device **1** of this embodiment includes the first power source **11** connected between the first node N**1** and the second node N**2**, and the second power source **12** connected between the third node N**3** and the fourth node N**4**. The power supply device **1** supplies power to an electrical load (such as the inverter **21**, the auxiliary VCU **23**, and the inlet **24**) connected between the first node N**1** and the fourth node N**4**.

[0087] The power supply device **1** includes the switch circuit **13**, the first reactor **14**, the second reactor **15**, and the control device **19**. The switch circuit **13** has the first switching element SW**1** connected between the first node N**1** and the third node N**3**, the second switching element SW**2** connected between the second node N**2** and the third node N**3**, and the third switching element SW**3** connected between the second node N**2** and the fourth node N**4**. The first reactor **14** is disposed between the first power source **11** and the first node N**1** or the second node N**2**, and the second reactor **15** is disposed between the second power source **12** and the third node N**3** or the fourth node N**4**.

[0088] The control device **19** alternately switches between the first state and the second state. The first state is a state in which the first power source **11** is connected between the first node N**1** and the fourth node N**4** via the first reactor **14**, and the second power source **12** is connected to both ends of the second reactor **15**. The second state is a state in which the first power source **11** is connected to both ends of the first reactor **14**.

[0089] When the first state is set, the control device **19** sets the second switching element SW**2** and the third switching element SW**3** of the switch circuit **13** to the closed state and sets the first switching element SW**1** to the open state. When the second state is set, the control device **19** sets the first switching element SW**1** and the second switching element SW**2** of the switch circuit **13** to the closed state and sets the third switching element SW**3** to the open state.

[0090] Thus, by simply switching between the open state and the closed state of the plurality of switching elements provided in the switch circuit **13**, a high frequency current can be applied to the first power source **11** and the second power source **12**, and thus the first power source **11** and the

second power source **12** can be heated more efficiently than before without increasing costs.
[0091] The above describes the form for carrying out the present invention using an embodiment, but the present invention is not limited to such an embodiment, and various modifications and substitutions can be made within the scope that does not deviate from the gist of the present invention. For example, in the above-described embodiment, the example in which the first reactor **14** is disposed between the first power source **11** and the second node N**2**, and the second reactor **15** is disposed between the second power source **12** and the third node N**3** has been described. However, the first reactor **14** may be disposed between the first power source **11** and the first node N**1**. Similarly, the second reactor **15** may be disposed between the second power source **12** and the fourth node N**4**.
[0092] The control device **19** can be realized by a computer such as an embedded computer. When the control device **19** is realized by a computer, functions of each unit of the control device **19** are realized by executing a program for realizing the functions in a central processing unit (CPU) provided in the computer. In other words, the functions of each unit of the control device **19** are realized by cooperation of software and hardware resources. The control device **19** may be realized using hardware such as a field-programmable gate array (FPGA), a large scale integration (LSI), or an application specific integrated circuit (ASIC).

Claims

1. A power supply device which includes a first power source connected between a first node and a second node, and a second power source connected between a third node and a fourth node, the power supply device supplying power to an electrical load connected between the first node and the fourth node, comprising: a switch circuit including a first switch connected between the first node and the third node, a second switch connected between the second node and the third node, and a third switch connected between the second node and the fourth node; a first reactor disposed between the first power source and the first node or the second node; a second reactor disposed between the second power source and the third node or the fourth node; and a control device configured to alternately switch between a first state in which the second switch and the third switch of the switch circuit are controlled to be in a closed state and the first switch is controlled to be in an open state, so that the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected to both ends of the second reactor and a second state in which the first switch and the second switch of the switch circuit are controlled to be in a closed state and the third switch is controlled to be in an open state, so that the second power source is connected between the first node and the fourth node via the second reactor and the first power source is connected to both ends of the first reactor.
2. The power supply device according to claim 1, wherein when switching between the first state and the second state is performed, the control device temporarily controls the first switch and the third switch to the open state and the second switch to the closed state to set a third state in which the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected between the first node and the fourth node via the second reactor.
3. The power supply device according to claim 1, further comprising a voltage detection unit configured to detect a voltage of each of the first power source and the second power source, wherein the control device performs balance control by alternately performing a first control in which the first switch is set to the closed state and the second switch and the third switch are set to the open state, and a second control in which the first switch, the second switch, and the third switch are set to the open state, when the voltage of the first power source is greater than the voltage of the second power source.
4. The power supply device according to claim 1, further comprising a voltage detection unit

configured to detect a voltage of each of the first power source and the second power source, wherein the control device performs balance control by alternately performing a third control in which the first switch and the second switch are set to the open state and the third switch is set to the closed state, and a second control in which the first switch, the second switch, and the third switch are set to the open state, when the voltage of the second power source is greater than the voltage of the first power source.

5. The power supply device according to claim 3, wherein the control device is configured to switch between a parallel state in which the first switch and the third switch are controlled to be in the closed state and the second switch is controlled to be in the open state, so that the first power source and the second power source are connected in parallel between the first node and the fourth node and a series state in which the first switch and the third switch are controlled to be in the open state and the second switch is controlled to be in the closed state, so that the first power source and the second power source are connected in series between the first node and the fourth node, and the balance control is performed when a difference between a voltage of the first power source and a voltage of the second power source detected by the voltage detection unit is greater than or equal to a predetermined reference value and a transition to the parallel state is instructed.

6. A method for controlling a power supply device which includes a first power source connected between a first node and a second node, and a second power source connected between a third node and a fourth node, and supplies power to an electrical load connected between the first node and the fourth node, wherein the power supply device includes a switch circuit including a first switch connected between the first node and the third node, a second switch connected between the second node and the third node, and a third switch connected between the second node and the fourth node, a first reactor disposed between the first power source and the first node or the second node, and a second reactor disposed between the second power source and the third node or the fourth node, the method includes a step of alternately switching between a first state in which the second switch and the third switch of the switch circuit are controlled to be in a closed state and the first switch is controlled to be in an open state, so that the first power source is connected between the first node and the fourth node via the first reactor and the second power source is connected to both ends of the second reactor and a second state in which the first switch and the second switch of the switch circuit are controlled to be in a closed state and the third switch is controlled to be in an open state, so that the second power source is connected between the first node and the fourth node via the second reactor and the first power source is connected to both ends of the first reactor.