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Alternating current generation circuit and temperature raising device

Abstract

An AC generation circuit includes a first capacitor having a first end connected to a positive electrode side of a power storage having an inductance component, a second capacitor having a first end connected to a negative electrode side of the power storage, a parallel switch unit configured to connect the first capacitor and the second capacitor to the power storage in parallel by connecting a second end of the first capacitor and the first end of the second capacitor and connecting the first end of the first capacitor and a second end of the second capacitor in accordance with a first control signal, a series switch unit configured to connect the first capacitor and the second capacitor to the power storage in series by connecting the second end of the first capacitor and the second end of the second capacitor in accordance with a second control signal, and an inductor connected between both terminals of the series switch unit.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
(1) Priority is claimed on Japanese Patent Application No. 2021-142596, filed Sep. 1, 2021, the content of which is incorporated herein by reference.
BACKGROUND OF THE INVENTION
Field of the Invention

(2) The present invention relates to an alternating current (AC) generation circuit and the temperature raising device.

Description of Related Art

(3) Efforts are underway to reduce adverse effects on the global environment (for example, reduction of NO.sub.x and SO.sub.x and reduction of CO.sub.2). Thus, in recent years, from the viewpoint of improving the global environment, for reduction of CO.sub.2, there is growing interest in at least electric vehicles allowed to travel with electric motors driven by power supplied by batteries (secondary batteries) such as, for example, a hybrid electric vehicle (HEV) and a plug-in hybrid vehicle (PHEV). The use of a lithium-ion secondary battery is being considered as a battery for in-vehicle use. In these electric vehicles, it is important to fully bring out the performance of the secondary battery. It is known that the charging/discharging performance of a secondary battery deteriorates when the temperature at the time of use drops below an appropriate range. It is possible to limit the deterioration of the charging/discharging performance of the secondary battery by raising the temperature to a suitable temperature at the time of use.

(4) In relation to this, for example, Japanese Patent No. 5293820 discloses technology related to a temperature raising device for raising the temperature of a secondary battery. In the temperature raising device disclosed in Japanese Patent No. 5293820, the temperature of the secondary battery is raised by positively generating a ripple current of a prescribed frequency of a frequency range in which an absolute value of impedance is relatively decreased in the secondary battery on the basis of frequency characteristics of impedance of the secondary battery.

SUMMARY OF THE INVENTION

(5) However, in the conventional technology, it may not be possible to raise the temperature of the secondary battery efficiently.

(6) The present invention has been made on the basis of the above recognition of the problems and an objective of the present invention is to provide an AC generation circuit and a temperature raising device capable of improving the energy efficiency by raising the temperature of a secondary battery more efficiently.

(7) An AC generation circuit and a temperature raising device according to the present invention adopt the following configurations.

(8) (1): According to an aspect of the present invention, there is provided an AC generation circuit for raising the temperature of a power storage by generating an AC current based on electric power stored in the power storage having an inductance component, the AC generation circuit including: a first capacitor having a first end connected to a positive electrode side of the power storage; a second capacitor having a first end connected to a negative electrode side of the power storage; a parallel switch unit configured to connect the first capacitor and the second capacitor to the power storage in parallel by connecting a second end of the first capacitor and the first end of the second capacitor and connecting the first end of the first capacitor and a second end of the second capacitor in accordance with a first control signal; a series switch unit configured to connect the first capacitor and the second capacitor to the power storage in series by connecting the second end of the first capacitor and the second end of the second capacitor in accordance with a second control signal; and an inductor connected between both terminals of the series switch unit.

(9) (2): In the above-described aspect (1), the parallel switch unit includes a first switch having a first terminal connected to the second end of the first capacitor and a second terminal connected to the first end of the second capacitor; and a second switch having a first terminal connected to the first end of the first capacitor and a second terminal connected to the second end of the second capacitor, wherein the series switch unit includes a third switch having a first terminal connected to the second end of the second capacitor and a second terminal connected to the second end of the first capacitor, and wherein the inductor is connected in parallel between the first terminal of the third switch and the second terminal of the third switch.

(10) (3): In the above-described aspect (2), inductance of the inductor is approximately one-third of

the inductance component.
(11) (4): In the above-described aspect (1), the parallel switch unit includes a first switch having a first terminal connected to the second end of the first capacitor and a second terminal connected to the first end of the second capacitor; and a second switch having a first terminal connected to the first end of the first capacitor and a second terminal connected to the second end of the second capacitor, the series switch unit includes a third switch having a first terminal connected to the second end of the second switch and a second terminal connected to the second end of the first capacitor; and a fourth switch having a first terminal connected to the second end of the second capacitor and a second terminal connected to the first terminal of the first switch, and the inductor includes a first inductor having a first end connected to the first terminal of the fourth switch and a second end connected to the second terminal of the third switch; a second inductor having a first end connected to the first end of the first inductor and a second end connected between the second terminal of the second switch and the first terminal of the third switch; and a third inductor having a first end connected between the first terminal of the first switch and the second terminal of the fourth switch and a second end connected to the second end of the first inductor.
(12) (5): In the above-described aspect (4), the inductance of the first inductor is approximately one-third of the inductance component.
(13) (6): In the above-described aspect (5), the inductance of the second inductor is equal to the inductance of the third inductor.
(14) (7): In the above-described aspect (1), the inductance component includes an inductance component provided in a wiring portion between the power storage and the AC generation circuit.
(15) (8): According to an aspect of the present invention, there is provided a temperature raising device including: the AC generation circuit according to the above-described aspect (1); and a controller configured to output a signal of a prescribed duty ratio for setting the parallel switch unit in a conductive state or a non-conductive state as the first control signal, output a signal of the prescribed duty ratio for setting the series switch unit in the conductive state or the non-conductive state as the second control signal, and alternately switch the state between a first state in which the parallel switch unit is in the conductive state and the series switch unit is in the non-conductive state and a second state in which the parallel switch unit is in the non-conductive state and the series switch unit is in the conductive state according to the first control signal and the second control signal.
(16) (9): In the above-described aspect (8), the prescribed duty ratio is approximately 50 percent.
(17) According to the above-described aspects (1) to (9), it is possible to improve the energy efficiency by raising the temperature of a secondary battery more efficiently.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a diagram showing an example of a configuration of a vehicle in which a temperature raising device according to an embodiment is adopted.
(2) FIG. **2** is a diagram showing an example of a configuration of an AC generation circuit provided in the temperature raising device according to a first embodiment.
(3) FIG. **3** is an example of a circuit equivalent to the AC generation circuit of the first embodiment.
(4) FIG. **4** is a diagram showing an example of a configuration of an AC generation circuit of a comparative example.
(5) FIG. **5** is an example of a circuit equivalent to the AC generation circuit of the comparative example.
(6) FIG. **6** is a diagram showing an example of an operation waveform of the AC generation circuit

of the comparative example.
(7) FIG. **7** is a diagram showing another example of the operation waveform of the AC generation circuit of the comparative example.
(8) FIG. **8** is a diagram showing an example of an operation waveform of the AC generation circuit of the first embodiment.
(9) FIG. **9** is a diagram showing another example of the operation waveform of the AC generation circuit of the first embodiment.
(10) FIG. **10** is a diagram showing another example of the operation waveform of the AC generation circuit of the comparative example.
(11) FIG. **11** is a diagram showing an example of a configuration of an AC generation circuit provided in the temperature raising device according to a second embodiment.
(12) FIG. **12** is an example of a circuit equivalent to the AC generation circuit of the second embodiment.
(13) FIG. **13** is a diagram showing an example of an operation waveform of the AC generation circuit of the second embodiment.
(14) FIG. **14** is a diagram showing another example of the operation waveform of the AC generation circuit of the second embodiment.
(15) FIG. **15** is a diagram for comparing characteristics between AC currents generated by AC generation circuits.
DETAILED DESCRIPTION OF THE INVENTION
(16) Hereinafter, embodiments of an AC generation circuit and a temperature raising device of the present invention will be described with reference to the drawings. As used throughout this disclosure, the singular forms “a,” “an,” and “the” include a plurality of references unless the context clearly dictates otherwise.
(17) [Configuration of Vehicle]
(18) FIG. **1** is a diagram showing an example of a configuration of a vehicle in which a temperature raising device according to an embodiment is adopted. A vehicle **1** is a hybrid electric vehicle (HEV) (hereinafter simply referred to as a “vehicle”) that travels by combining driving of an electric motor driven using electric power supplied from a battery (a secondary battery) for traveling and driving of an internal combustion engine using fuel as an energy source, such as, for example, a diesel engine or a gasoline engine. Vehicles to which the present invention is applied may be, for example, general vehicles such as four-wheeled vehicles, saddle-riding type two-wheeled vehicles, three-wheeled vehicles (including two front wheel and one rear wheel vehicles in addition to one front wheel and two rear wheel vehicles), and a vehicle that travels using an electric motor driven by power supplied from a battery for traveling such as an assisted bicycle. The vehicle **1** may be, for example, an electric vehicle (EV) that travels according to driving of only an electric motor.
(19) The vehicle **1** includes, for example, an engine **10**, a motor **12**, a speed reducer **14**, drive wheels **16**, a power drive unit (PDU) **20**, a battery **30**, a battery sensor **32**, a temperature raising device **40**, driving operation elements **70**, a vehicle sensor **80**, and a control device **100**.
(20) The engine **10** is an internal combustion engine that outputs motive power by burning fuel, for example, such as light oil or gasoline, stored in a fuel tank (not shown) of the vehicle **1** and operating (rotating) the engine **10**. The engine **10** is a reciprocating engine including, for example, a cylinder and a piston, an intake valve, an exhaust valve, a fuel injection device, an ignition plug, a conrod, a crankshaft, and the like. The engine **10** may be a rotary engine. The rotational power of the engine **10** is transferred to the speed reducer **14**.
(21) The motor **12** is an electrical rotating machine for traveling of the vehicle **1**. The motor **12** is, for example, a three-phase AC motor. The rotor of the motor **12** is connected to the speed reducer **14**. The motor **12** is driven (rotated) by electric power supplied from the battery **30** via the PDU **20**. The rotational power of the motor **12** is transferred to the speed reducer **14**. The motor **12** may

operate as a regenerative brake using kinetic energy of the vehicle **1** during deceleration to generate electric power. The motor **12** may include an electric motor for power generation. The electric motor for power generation uses, for example, the rotational power output by the engine **10** to generate electric power.

(22) The speed reducer **14** is, for example, a differential gear. The speed reducer **14** allows a driving force of the shaft to which the engine **10** and the motor **12** are connected, i.e., the rotational power of the engine **10** and the motor **12**, to be transferred to the axle to which the drive wheels **16** are connected. The speed reducer **14** may include, for example, a so-called transmission mechanism in which a plurality of gears or shafts are combined to change the rotational speed of the engine **10** or the motor **12** in accordance with a gear ratio and allow the rotational speed to be transferred to the axle. The speed reducer **14** may also include, for example, a clutch mechanism that directly connects or separates the rotational power of the engine **10** or the motor **12** to or from the axle.

(23) The PDU **20** is, for example, an inverter, a direct current (DC)-DC converter, or an AC-DC converter. The PDU **20** converts the DC power supplied from the battery **30** into three-phase AC power for driving the motor **12** and outputs the AC power to the motor **12**. The PDU **20** may include, for example, a voltage control unit (VCU) that boosts the DC power supplied from the battery **30**. The PDU **20** converts the three-phase AC power generated by the motor **12** operating as a regenerative brake into DC power and outputs the DC power to the battery **30**. The voltage of the PDU **20** may be boosted or lowered in accordance with the power output destination and the boosted or lowered voltage may be output. Although the components of the PDU **20** are shown as a single unitary configuration in FIG. **1**, this is only an example and the components provided in the PDU **20** may be decentralized and arranged in the vehicle **1**.

(24) The battery **30** is a battery for traveling of the vehicle **1**. The battery **30** is, for example, a battery including a secondary battery capable of iteratively being charged and discharged as a power storage unit such as a lithium-ion battery. The battery **30** may have a configuration that can be easily attached to and detached from the vehicle **1**, such as a cassette type battery pack, or may have a stationary configuration that is not easily attached to and detached from the vehicle **1**. The secondary battery provided in the battery **30** is, for example, a lithium-ion battery. Although, for example, a capacitor such as an electric double layer capacitor, a composite battery in which a secondary battery and a capacitor are combined, and the like as well as a lead storage battery, a nickel-hydrogen battery, a sodium ion battery, and the like can be considered for the secondary battery provided in the battery **30**, the secondary battery may have any configuration. The battery **30** stores (is charged with) electric power introduced from an external charger (not shown) of the vehicle **1** and is discharged to supply the stored power such that the vehicle **1** is allowed to travel. The battery **30** stores (is charged with) the electric power generated by the motor **12** operated as a regenerative brake supplied via the PDU **20** and is discharged to supply the stored electric power for traveling (for example, accelerating) of the vehicle **1**. The battery **30** has at least an inductance component.

(25) The battery **30** is an example of a “power storage” in the claims and the inductance component connected to the power storage unit provided in the battery **30** is an example of an “inductance component” in the claims.

(26) A battery sensor **32** is connected to the battery **30**. The battery sensor **32** detects physical quantities such as a voltage, a current, and the temperature of the battery **30**. The battery sensor **32** includes, for example, a voltage sensor, a current sensor, and a temperature sensor. The battery sensor **32** detects the voltage of the battery **30** using the voltage sensor, detects the current of the battery **30** using the current sensor, and detects the temperature of the battery **30** using the temperature sensor. The battery sensor **32** outputs information such as a detected voltage value, current value, and temperature of the battery **30** (hereinafter referred to as “battery information”) to the control device **100**.

(27) The temperature raising device **40** raises the temperature of the battery **30** in accordance with control from the control device **100**. The temperature raising device **40** includes, for example, an AC generation circuit **42** and a controller **44**.
(28) The AC generation circuit **42** includes, for example, a first capacitor connected to a positive electrode side of the battery **30**, a second capacitor connected to a negative electrode side of the battery **30**, a parallel switch unit in which the first capacitor and the second capacitor are connected to the battery **30** in parallel, a series switch unit in which the first capacitor and the second capacitor are connected to the battery **30** in series, and an inductor connected between both terminals of the series switch unit. The AC generation circuit **42** generates an AC current using a resonance operation between the inductance component provided in the battery **30** and at least the first capacitor. More specifically, the AC generation circuit **42** generates an AC current based on electric power stored in the battery **30** according to a resonance operation in which magnetic energy stored in the inductance component provided in the battery **30** and electrostatic energy stored in at least the first capacitor are alternately exchanged. The AC generation circuit **42** raises the temperature of the battery **30** by applying the generated AC current to the battery **30** (allowing the generated AC current to flow through the battery **30**).
(29) The controller **44** switches the connection of the first capacitor and the second capacitor to the battery **30** to either the parallel connection or the serial connection by setting each of the parallel switch unit and the series switch unit provided in the AC generation circuit **42** in a conductive state or a non-conductive state. More specifically, the controller **44** alternately switches the state between a state in which the first capacitor and the second capacitor are connected to the battery **30** in parallel by setting the parallel switch unit in the conductive state and setting the series switch unit in the non-conductive state and a state in which the first capacitor and the second capacitor are connected to the battery **30** in series by setting the parallel switch unit in the non-conductive state and setting the series switch unit in the conductive state. At this time, the controller **44** may provide a period during which both the parallel switch unit and the series switch unit are in the non-conductive state, i.e., a so-called dead time, and switch the connection of the first capacitor and the second capacitor to the battery **30** from a parallel connection to a series connection or vice versa.
(30) A state in which the first capacitor and the second capacitor are connected to the battery **30** in parallel is an example of a “first state” in the claims and a state in which the first capacitor and the second capacitor are connected to the battery **30** in series is an example of a “second state” in the claims. Details of the temperature raising device **40** and the components provided in the temperature raising device **40** will be described below.
(31) The driving operation elements **70** include, for example, an accelerator pedal, a brake pedal, a shift lever, a steering wheel, a variant steering wheel, a joystick, and other operation elements. The driving operation element **70** is equipped with a sensor that detects the presence or absence of an operation of a user (a driver) of the vehicle **1** on each operation element or an amount of operation. The driving operation element **70** outputs a detection result of the sensor to the control device **100**.
(32) The vehicle sensor **80** detects a traveling state of the vehicle **1**. The vehicle sensor **80** includes, for example, a vehicle speed sensor that detects the speed of the vehicle **1** and an acceleration sensor that detects the acceleration of the vehicle **1**. The vehicle sensor **80** outputs a detection result detected by each sensor to the control device **100**.
(33) The control device **100** controls an operation of the engine **10** or the motor **12** in accordance with a detection result output by each sensor provided in the driving operation element **70**, i.e., an operation of the user (the driver) of the vehicle **1** on each operation element. In other words, the control device **100** controls a driving force of the motor **12**. The control device **100** may include, for example, separate control devices such as an engine control unit, a motor control unit, a battery control unit, a PDU control unit, and a VCU control unit. For example, the control device **100** may be replaced with a control device such as an engine electronic control unit (ECU), a motor ECU, a battery ECU, a PDU-ECU, or a VCU-ECU.

(34) The control device **100** controls a supply amount of AC power supplied from the battery **30** to the motor **12** and the frequency (i.e., a voltage waveform) of the AC power to be supplied when the vehicle **1** travels. At this time, the control device **100** controls the activation of the temperature raising device **40** on the basis of information of the temperature of the battery **30** included in the battery information output by the battery sensor **32**. That is, the control device **100** controls the activation or stopping of the temperature raising device **40** such that the temperature of the battery **30** is increased (raised) to a temperature suitable for use to limit the deterioration of the charging/discharging performance of the battery **30**.
(35) The control device **100** operates, for example, when a hardware processor such as a central processing unit (CPU) executes a program (software). The control device **100** may be implemented by hardware (including a circuit unit; circuitry) such as a large-scale integration (LSI) circuit, an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or a graphics processing unit (GPU) or may be implemented by software and hardware in cooperation. The control device **100** may be implemented by a dedicated LSI circuit. The program may be pre-stored in a storage device (a storage device including a non-transitory storage medium) such as a hard disk drive (HDD) or a flash memory provided in the vehicle **1** or may be stored in a removable storage medium (a non-transitory storage medium) such as a DVD or a CD-ROM and installed in the HDD or the flash memory provided in the vehicle **1** when the storage medium is mounted in the drive device provided in the vehicle **1**.
First Embodiment
(36) [Configuration of AC Generation Circuit Provided in Temperature Raising Device]
(37) FIG. **2** is a diagram showing an example of a configuration of an AC generation circuit **42** (hereinafter referred to as an “AC generation circuit **42-1**”) provided in the temperature raising device **40** according to a first embodiment. In FIG. **2**, a battery **30** related to the AC generation circuit **42-1** is also shown. In the battery **30**, for example, resistance Ra and inductance La are connected to a positive electrode side of a power storage unit Ba in series. The inductance La connected to the power storage unit Ba provided in the battery **30** is an example of an “inductance component” in the claims.
(38) The AC generation circuit **42-1** includes, for example, a capacitor C**1**, a capacitor C**2**, a switch S**1**, a switch S**2**, a switch S**3**, and an inductor L**3**. The capacitor C**1** and the capacitor C**2** are capacitors having the same capacitance. Control is performed such that each of the switch S**1**, the switch S**2**, and the switch S**3** is in a conductive state (a closed state) in which a connection between both terminals thereof is made or a non-conductive state (an open state) in which the connection between both terminals thereof is disconnected in accordance with a control signal output by the controller **44**. In the following description, a control signal for controlling the switch S**1** output by the controller **44** such that it is in the conductive state or the non-conductive state is referred to as a “control signal CS**1**,” a control signal for controlling the switch S**2** such that it is in the conductive state or the non-conductive state is referred to as a “control signal CS**2**,” and a control signal for controlling the switch S**3** such that it is in the conductive state or the non-conductive state is referred to as a “control signal CS**3**.”
(39) Each of the switch S**1**, the switch S**2**, and the switch S**3** may be a semiconductor switching element that is controlled such that it is in an ON state or an OFF state such as, for example, an N-channel type metal oxide semiconductor field effect transistor (MOSFET). In this case, for example, a configuration in which diodes functioning as freewheeling diodes are further connected in parallel may be adopted. When each of the switch S**1**, the switch S**2**, and the switch S**3** is composed of a semiconductor switching element, the controller **44** outputs a gate signal for setting the semiconductor switching element in the ON state or the OFF state as a control signal for controlling each of the switch S**1**, the switch S**2**, and the switch S**3** such that it is in the conductive state or the non-conductive state.
(40) In the AC generation circuit **42-1**, a first end of the capacitor C**1** is connected to the positive

electrode side of the battery **30** and a first end of the capacitor C**2** is connected to the negative electrode side of the battery **30**. Further, in the AC generation circuit **42-1**, a first terminal of the switch S**2** is connected to the first end of the capacitor C**1** and a second terminal of the switch S**1** is connected to the first end of the capacitor C**2**. In the AC generation circuit **42-1**, the first terminal of the switch S**1** and a second terminal of the switch S**3** are connected to a second end of the capacitor C**1** and a second terminal of the switch S**2** and a first terminal of the switch S**3** are connected to a second end of the capacitor C**2**. Further, in the AC generation circuit **42-1**, the inductor L**3** is connected in parallel between the first terminal and the second terminal of the switch S**3**.

(41) According to such a configuration, in the AC generation circuit **42-1**, the capacitor C**1** and the capacitor C**2** are connected in parallel or in series between the positive electrode side and the negative electrode side of the battery **30** in accordance with control from the controller **44**. More specifically, the controller **44** allows the capacitor C**1** and the capacitor C**2** to be connected in parallel between the positive electrode side and the negative electrode side of the battery **30** by outputting a control signal CS**1** for setting the switch S**1** in the conductive state to the switch S**1**, outputting a control signal CS**2** for setting the switch S**2** in the conductive state to the switch S**2**, and outputting a control signal CS**3** for setting the switch S**3** in the non-conductive state to the switch S**3**. On the other hand, the controller **44** allows the capacitor C**1** and the capacitor C**2** to be connected in series between the positive electrode side and the negative electrode side of the battery **30** by outputting a control signal CS**1** for setting the switch S**1** in the non-conductive state to the switch S**1**, outputting a control signal CS**2** for setting the switch S**2** in the non-conductive state to the switch S**2**, and outputting a control signal CS**3** for setting the switch S**3** in the conductive state to the switch S**3**.

(42) In the AC generation circuit **42-1**, the capacitor C**1** is an example of a “first capacitor” in the claims and the capacitor C**2** is an example of a “second capacitor” in the claims. In the AC generation circuit **42-1**, a configuration in which the switch S**1** and the switch S**2** are combined is an example of a “parallel switch unit” in the claims and the switch S**3** is an example of a “series switch unit” in the claims. In the AC generation circuit **42-1**, the switch S**1** is an example of a “first switch” in the claims, the switch S**2** is an example of a “second switch” in the claims, and the switch S**3** is an example of a “third switch” in the claims. In the AC generation circuit **42-1**, the inductor L**3** is an example of an “inductor” in the claims. The control signal CS**1** output to the switch S**1** by the controller **44** and the control signal CS**2** output to the switch S**2** are examples of a “first control signal” in the claims and the control signal CS**3** output to the switch S**3** by the controller **44** is an example of a “second control signal” in the claims. In the AC generation circuit **42-1**, a state in which the capacitor C**1** and the capacitor C**2** are connected in parallel between the positive electrode side and the negative electrode side of the battery **30** is an example of a “first state” in the claims and a state in which the capacitor C**1** and the capacitor C**2** are connected in series between the positive electrode side and the negative electrode side of the battery **30** is an example of a “second state” in the claims.

(43) [Operation of Temperature Raising Device]

(44) Here, the frequency of an AC current generated by the AC generation circuit **42-1** is considered. It is preferable that the current waveform of the AC current generated by the AC generation circuit **42-1** be a sinusoidal wave such that the temperature of the battery **30** is efficiently raised by the temperature raising device **40**. From the viewpoint of control for allowing the AC generation circuit **42-1** to generate an AC current, it is preferable that the duty ratio of the control signal output to each of the switch S**1**, the switch S**2**, and the switch S**3** by the controller **44** be 50 percent (%).

(45) By the way, as described above, in the AC generation circuit **42-1**, the capacitor C**1** and the capacitor C**2** are capacitors having the same capacitance. Thus, in the AC generation circuit **42-1**, the total capacitance when the capacitor C**1** and the capacitor C**2** are considered as one capacitor is

different between a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series and a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel. More specifically, the total capacitance of the AC generation circuit **42-1** when the capacitor C**1** and the capacitor C**2** are connected in series is a sum of reciprocals of capacitance values of the capacitors, i.e., capacitance multiplied by ½. On the other hand, the total capacitance of the AC generation circuit **42-1** when the capacitor C**1** and the capacitor C**2** are connected in parallel is a sum of the capacitance values of the capacitors, i.e., capacitance multiplied by 2. Thus, in the AC generation circuit **42-1**, the frequency of the generated AC current is different between a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series and a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel.

(46) FIG. **3** is an example of a circuit equivalent to the AC generation circuit **42-1** of the first embodiment. An equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series is shown in (a) of FIG. **3** and an equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel is shown in (b) of FIG. **3**. In FIG. **3**, an inductance component of the inductance La provided in the battery **30** is denoted by “Ls” and a resistance component of the resistance Ra is denoted by “Rs.” The capacitance of the capacitors C**1** and C**2** is denoted by “Cx” and the inductance of the inductor L**3** is denoted by “Ly.”

(47) As shown in (a) of FIG. **3**, when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series in the AC generation circuit **42-1**, the inductor L**3** is short-circuited by the switch S**3**. On the other hand, when the capacitor C**1** and the capacitor C**2** are connected in parallel to the battery **30** in the AC generation circuit **42-1**, the inductor L**3** is arranged between the capacitor C**1** and the capacitor C**2**. In this way, it is possible to make a current waveform of a generated AC current closer to a sinusoidal wave and facilitate each switch control process of the controller **44** (make the duty ratio of the control signal output by the controller **44** close to 50%) by arranging the inductor L**3** when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-1**.

Comparative Examples

Configuration of AC Generation Circuit in Comparative Example

(48) Here, an AC generation circuit (hereinafter referred to as an “AC generation circuit **42-**C”) of a comparative example in which the inductor L**3** is not provided will be first described to show the effects of the inductor L**3** provided in the AC generation circuit **42-1**. FIG. **4** is a diagram showing an example of a configuration of the AC generation circuit **42-**C of a comparative example. The AC generation circuit **42-**C has a configuration in which the inductor L**3** is omitted from the AC generation circuit **42-1**. A connection of a capacitor C**1**, a capacitor C**2**, a switch S**1**, a switch S**2**, and a switch S**3** in the AC generation circuit **42-**C is equivalent to that in the AC generation circuit **42-1**.

(49) FIG. **5** is an example of a circuit equivalent to the AC generation circuit **42-**C of the comparative example. An equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series in the AC generation circuit **42-**C is shown in (a) of FIG. **5** and an equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel in the AC generation circuit **42-**C is shown in (b) of FIG. **5**. Even in FIG. **5**, as in the circuit equivalent to the AC generation circuit **42-1** shown in FIG. **3**, an inductance component of inductance La provided in the battery **30** is denoted by “Ls,” a resistance component of resistance Ra is denoted by “Rs,” and capacitance of the capacitor C**1** and the capacitor C**2** is denoted by “Cx.”

(50) First, the frequency of an AC current generated by the AC generation circuit **42-**C will be described with reference to FIG. **5**. In the AC generation circuit **42-**C, impedance Z when the capacitor C**1** and the capacitor C**2** are connected in series as shown in (a) of FIG. **5** can be obtained by the following Eq. (1).

(51) $Z = ZLs + 2ZCx + Rs = j\omega\text{Ls} + \frac{2}{J\omega Cx} + Rs = j(\omega\text{Ls} - \frac{2}{\omega\text{Cx}}) + Rs$ (1)

(52) A resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series in the AC generation circuit **42**-C can be obtained by the following Eq. (2).

(53) $\omega s = \sqrt{2}\ \text{.Math.}\ \frac{1}{\sqrt{\text{Cx .Math. Ls}}}$ (2)

(54) On the other hand, in the AC generation circuit **42**-C, impedance Z when the capacitor C**1** and the capacitor C**2** are connected in parallel as shown in (b) of FIG. **5** can be obtained by the following Eq. (3).

(55) $Z = \text{ZLs} + \frac{\text{ZCx}}{2} + \text{Rs} = j\omega\text{Ls} + \frac{1}{2j\omega\text{Cx}} + \text{Rs} = \frac{1-2\omega^2\text{LsCx}}{2j\omega\text{Cx}} + \text{Rs}$ (3)

(56) A resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42**-C can be obtained by the following Eq. (4).

(57) $\omega p = \frac{1}{\sqrt{2}}\ \text{.Math.}\ \frac{1}{\sqrt{\text{Cx .Math. Ls}}}$ (4)

(58) Here, in the AC generation circuit **42**-C, when the resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series is compared with the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel, a ratio represented by the following Eq. (5) is obtained.

$\omega s{:}\omega p=2{:}1$ (5)

(59) That is, in the AC generation circuit **42**-C, a resonance frequency differs according to a total capacitance difference between a case where the capacitor C**1** and the capacitor C**2** are connected in series and a case where the capacitor C**1** and the capacitor C**2** are connected in parallel. More specifically, a resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in series becomes twice a resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in parallel. Thus, in the AC generation circuit **42**-C, the current waveform of the generated AC current does not become a sinusoidal wave, but becomes an asymmetric current waveform when the current value is positive and when the current value is negative. Thus, in the AC generation circuit **42**-C, a large number of harmonic components are included in the generated AC current and a large amount of noise is radiated when the temperature of the battery **30** is raised.

(60) In order to generate the AC current having a maximum amplitude in the AC generation circuit **42**-C, the controller **44** is required to output a control signal for switching a connection of the capacitor C**1** and the capacitor C**2** to the battery **30** to the series connection or the parallel connection at a ratio between series connection="1" and parallel connection="2," i.e., a duty ratio of 1:2. In other words, when the controller **44** outputs a control signal having a duty ratio of 50% to each switch, the controller **44** cannot generate an AC current having the maximum amplitude.

Operation of Temperature Raising Device in Comparative Example

(61) FIG. **6** is a diagram showing an example of an operation waveform (a simulation waveform) of the AC generation circuit **42**-C of the comparative example. An example of control signals output to the switches by the controller **44** and changes in the AC current and the output voltage within the AC generation circuit **42**-C is shown in (a) of FIG. **6** and the AC current flowing into the AC generation circuit **42**-C is shown in (b) of FIG. **6**.

(62) More specifically, the control signal CS**1**, the control signal CS**2**, and the control signal CS**3** output to the switches by the controller **44** for allowing the AC generation circuit **42**-C to generate the AC current are shown in (a) of FIG. **6**. In (a) of FIG. **6**, it is assumed that the corresponding switch is in the conductive state by setting the control signal CS**1**, the control signal CS**2**, and the control signal CS**3** at a "High" level and the corresponding switch is in the non-conductive state by setting the control signal CS**1**, the control signal CS**2**, and the control signal CS**3** at a "Low" level. An operation waveform shown in (a) of FIG. **6** is an example where the controller **44** performs a control process by outputting a control signal whose duty ratio is 50% to each switch such that the AC generation circuit **42**-C is allowed to generate an AC current of a sinusoidal wave. Although the controller **44** may provide a dead time for setting all the switches in the non-conductive state

between a period in which the switch is set in the conductive state and a period in which the switch is set in the non-conductive state as described above, a case where the controller **44** controls each switch without providing the dead time is shown in (a) of FIG. **6**.
(63) In (a) of FIG. **6**, an example of changes in a voltage V**1**-V**0** between both electrodes of the battery **30** (including the inductance La), a current I-C**1** flowing through the capacitor C**1**, and a current I-C**2** flowing through the capacitor C**2**, and a current I-E**1** flowing through the battery **30** (including the inductance La) that are changed when the controller **44** controls the control signal CS**1**, the control signal CS**2**, and the control signal CS**3** is shown. In (b) of FIG. **6**, an example of a measurement position of the voltage V**1**-V**0** and a direction in which each of the current I-C**1**, the current I-C**2**, and the current I-E**1** flows is shown.
(64) As shown in (a) of FIG. **6**, the controller **44** allows the current I-C**1** and the current I-C**2** to flow from a positive region to a negative region and also allows the current I-E**1** to flow from the positive region to the negative region in a series connection period PS in which the control signal CS**1** and the control signal CS**2** are set at the "Low" level and the control signal CS**3** is set at the "High" level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42**-C decreases from a positive peak voltage to a negative peak voltage and then increases. On the other hand, the controller **44** allows the current I-C**1** and the current I-C**2** to flow from the negative region to the positive region and also allows the current I-E**1** to flow from the negative region to the positive region in a parallel connection period PP in which the control signal CS**1** and the control signal CS**2** are set at the "High" level and the control signal CS**3** is set at the "Low" level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42**-C increases toward the positive peak voltage following the series connection period PS.
(65) In this way, the AC generation circuit **42**-C can generate an AC current when the controller **44** outputs a control signal to each switch and switches the connection of the capacitor C**1** and the capacitor C**2** to the battery **30** to the series connection or the parallel connection. However, as can be seen from the waveforms of the current I-E**1** and the voltage V**1**-V**0** in each of the series connection period PS and the parallel connection period PP shown in (a) of FIG. **6**, the amplitude of the current waveform of the AC current generated by the AC generation circuit **42**-C becomes small. Thus, as described above, the controller **44** is required to output the control signal with a duty ratio of 1:2 such that the AC current having the maximum amplitude is generated in the AC generation circuit **42**-C.
(66) Here, an operation of a case where the controller **44** allows the AC generation circuit **42**-C to generate an AC current having a maximum amplitude by outputting a control signal having a duty ratio of 1:2 to each switch such that a difference in the current waveform of the AC current according to the duty ratio of the control signal is shown will be described. FIG. **7** is a diagram showing another example of an operation waveform (a simulation waveform) of the AC generation circuit **42**-C of the comparative example. Even in FIG. **7**, control signals and a voltage and a current changed with the control signals are shown as in the example of the operation waveform of the AC generation circuit **42**-C in the control signal of the duty ratio of 50% shown in (a) of FIG. **6**. That is, in FIG. **7**, an example of control signals output by the controller **44** and changes in a voltage V**1**-V**0** between both electrodes of the battery **30** (including the inductance La) and a current I-C**1**, a current I-C**2**, and a current I-E**1** flowing through the components, which change with the control signals, is shown. As in the example of the operation waveform of the AC generation circuit **42**-C shown in FIG. **6**, the operation waveform shown in FIG. **7** is also an example of a case where the controller **44** controls each switch without providing a dead time. Even in the example shown in FIG. **7**, an example of a measurement position of the voltage V**1**-V**0** and a direction in which each of the current I-C**1**, the current I-C**2**, and the current I-E**1** flows is similar to an example shown in (b) of FIG. **6**.
(67) As shown in FIG. **7**, the current I-C**1** and the current I-C**2** flow in the positive region and the current I-E**1** also flows in the positive region in the series connection period PS shortened by the

controller **44** outputting the control signal at the duty ratio of 1:2. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42**-C drops from the positive peak voltage to the negative peak voltage. On the other hand, in the parallel connection period PP which is lengthened by the controller **44** outputting the control signal at the duty ratio of 1:2, the current I-C**1** and the current I-C**2** flow in the negative region, such that the current I-E**1** also flows in the negative region. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42**-C rises from the negative peak voltage to the positive peak voltage.

(68) As described above, in the AC generation circuit **42**-C, the controller **44** outputs a control signal to each switch at a duty ratio of 1:2, such that it is possible to generate an AC current having a larger amplitude (a maximum amplitude), as can be seen by comparing the waveforms of currents I-E**1** and voltages V**1**-V**0** of the series connection period PS and the parallel connection period PP in each of (a) of FIG. **6** and FIG. **7**. However, when the controller **44** switches the connection of the capacitor C**1** and the capacitor C**2** to the battery **30** to a series connection or a parallel connection at a duty ratio of 1:2, the current waveform of the AC current generated by the AC generation circuit **42**-C is not a sinusoidal wave and the amplitude thereof is also different between positive and negative regions of the AC current, as can be seen from the waveforms of the currents I-E**1** and the voltages V**1**-V**0** of the series connection period PS and the parallel connection period PP in FIG. **7**.

(69) The frequency of the AC current generated by the AC generation circuit **42-1** will be described with reference to FIG. **3** again. First, a resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in series shown in (a) of FIG. **3** is taken into account. When the capacitor C**1** and the capacitor C**2** are connected in series in the AC generation circuit **42-1**, Ly=0 because the inductor L**3** is short-circuited by the switch S**3** as described above. Accordingly, even in the AC generation circuit **42-1**, the impedance Z when the capacitor C**1** and the capacitor C**2** are connected in series can be obtained as shown in the above Eq. (1) as in the AC generation circuit **42**-C and the resonance frequency cos can be obtained as shown in the above Eq. (2).

(70) Next, the resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in parallel shown in (b) of FIG. **3** is taken into account. When the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-1**, the inductor L**3** is arranged between the capacitor C**1** and the capacitor C**2** as described above. Thus, in the AC generation circuit **42-1**, the impedance Z when the capacitor C**1** and the capacitor C**2** are connected in parallel can be obtained as shown in the following Eq. (6), unlike the AC generation circuit **42**-C.

(71) $$Z = ZLs + \frac{1}{\frac{2}{ZCx} + \frac{1}{ZLy}} + Rs = ZLs + \frac{ZCx \cdot ZLy}{ZCx + 2ZLy} + Rs \quad (6)$$
$$= j\omega Ls + \frac{\frac{1}{j\omega Cx} \cdot j\omega Ly}{\frac{1}{j\omega Cx} + 2j\omega Ly} + Rs = j\omega Ls + \frac{\frac{Ly}{Cx}}{\frac{1}{j\omega Cx} + 2j\omega Ly} + Rs$$
$$= \frac{j\omega Ls(\frac{1}{j\omega Cx} + 2j\omega Ly) + \frac{Ly}{Cx}}{\frac{1}{j\omega Cx} + 2j\omega Ly} + Rs = \frac{Ls(\frac{1}{Cx} - 2\omega^2 Ly) + \frac{Ly}{Cx}}{\frac{1}{j\omega Cx} + 2j\omega Ly} + Rs = \frac{\frac{Ls + Ly}{Cx} - 2\omega^2 LsLy}{\frac{1}{j\omega Cx} + 2j\omega Ly} + Rs$$

(72) The resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-1** can be obtained as shown in the following Eq. (7).

(73) $$\omega p = \frac{1}{\sqrt{2}} \cdot \sqrt{\frac{Ls + Ly}{Cx \cdot Ls \cdot Ly}} \quad (7)$$

(74) From this, in the AC generation circuit **42-1**, it is only necessary to establish the following Eq. (9) because the resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series is equal to the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel (the following Eq. (8) is given).

(75) $$\omega s = \omega p \quad (8) \qquad \frac{2}{Cx \cdot Ls} = \frac{Ls + Ly}{2 \cdot Cx \cdot Ls \cdot Ly} \quad (9)$$

(76) From this, it is only necessary to provide the inductance Ly of the inductor L**3** in the AC generation circuit **42-1** such that the following Eq. (10) is established.

(77) $$Ly = \frac{Ls}{3} \quad (10)$$

(78) That is, if the inductance Ly of the inductor L**3** is set to one-third of the inductance component

Ls of the inductance La provided in the battery **30**, the resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series can be made equal to the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-1**.

(79) FIG. **8** is a diagram showing an example of an operation waveform (a simulation waveform) of the AC generation circuit **42-1** of the first embodiment. In FIG. **8**, control signals and a voltage and a current that change with the control signals are also shown as in the case of the operation waveform of the AC generation circuit **42**-C of the comparative example shown in FIG. **6** or **7**. That is, an example of changes in control signals output by the controller **44** and changes in a voltage V**1**-V**0** between both electrodes of the battery **30** (including the inductance La) and a current I-C**1**, a current I-C**2**, and a current I-E**1** flowing through the components, which change with the control signals, is shown in (a) of FIG. **8** and an example of a measurement position of the voltage V**1**-V**0** and a direction in which each of the current I-C**1**, the current I-C**2**, and the current I-E**1** flows is shown in (b) of FIG. **8**.

(80) The operation waveform shown in (a) of FIG. **8** is an example of a case where the controller **44** outputs a control signal having a duty ratio of 50% to each switch such that the AC generation circuit **42-1** is allowed to generate an AC current of a sinusoidal wave. As in the example of the operation waveform of the AC generation circuit **42**-C shown in FIG. **6** or **7**, the operation waveform shown in (a) of FIG. **8** is also an example of a case where the controller **44** controls each switch without providing a dead time.

(81) As shown in (a) of FIG. **8**, in the AC generation circuit **42-1**, the current I-E**1** also flows mainly in the negative region when the current I-C**1** and the current I-C**2** flow mainly in the negative region in the series connection period PS in which the controller **44** sets the control signal CS**1** and the control signal CS**2** at the “Low” level and sets the control signal CS**3** at the “High” level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-1** rises from the negative peak voltage to the positive peak voltage. On the other hand, in the AC generation circuit **42-1**, the current I-E**1** also flows mainly in the positive region when the current I-C**1** and the current I-C**2** flow mainly in the positive region in the parallel connection period PP in which the controller **44** sets the control signal CS**1** and the control signal CS**2** at the “High” level and sets the control signal CS**3** at the “Low” level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-1** drops from the positive peak voltage to the negative peak voltage.

(82) In this way, the controller **44** can allow an AC current to be generated as in the AC generation circuit **42**-C even in the AC generation circuit **42-1**, when the controller **44** outputs a control signal to each switch and switches the connection of the capacitor C**1** and the capacitor C**2** to the battery **30** to the series connection or the parallel connection. Moreover, as can be seen from the waveforms of the current I-E**1** and the voltage V**1**-V**0** in each of the series connection period PS and the parallel connection period PP shown in (a) of FIG. **8**, the current waveform of the AC current generated by the AC generation circuit **42-1** is closer to a sinusoidal wave than the current waveform of the AC current generated by the AC generation circuit **42**-C shown in (a) of FIG. **6** or FIG. **7** and the amplitude thereof also has a smaller absolute value difference between the positive region and the negative region of the AC current.

(83) In this way, in the AC generation circuit **42-1**, when the capacitor C**1** and the capacitor C**2** are connected in parallel, the inductor L**3** is configured to be arranged between the capacitor C**1** and the capacitor C**2**, such that the duty ratio of the control signal output by the controller **44** can be set to 50% and the current waveform of the generated AC current can be made closer to a sinusoidal wave. That is, the AC generation circuit **42-1** can generate an AC current having a symmetric current waveform when the current value is positive and when the current value is negative. Thereby, in the AC generation circuit **42-1**, it is possible to facilitate the control of each switch in the controller **44** and raise the temperature of the battery **30** more efficiently according to the generated AC current having a current waveform close to the sinusoidal wave. In other words, in

the AC generation circuit **42-1**, it is possible to generate an AC current with a reduced harmonic component and it is possible to reduce radiated noise when raising the temperature of the battery **30**.

(84) From this, the AC generation circuit **42-1** is more easily applied because it has a configuration in which the temperature is raised, and the change (a so-called ripple of a voltage waveform) in the entire voltage obtained by a combination of a plurality of batteries **30** is reduced, by applying an AC current to each battery **30** (allowing an AC current to flow through each battery **30**), for example, when the battery **30** mounted in the vehicle **1** has a configuration in which a plurality of (for example, two) batteries **30** are combined. More specifically, the AC generation circuit **42-1** is more easily applied because it has a configuration in which, when the battery **30** mounted in the vehicle **1** has a configuration in which two batteries **30** are combined, one AC generation circuit **42-1** is connected to each battery **30**, the controller **44** performs a control process in which a phase of the AC current generated by each AC generation circuit **42-1** is shifted (shifted by 180°), and therefore the change in the entire voltage output by a combination of two batteries **30** is reduced.

(85) [Another Operation of Temperature Raising Device]

(86) FIG. **9** is a diagram showing another example of an operation waveform (a simulation waveform) of the AC generation circuit **42-1** of the first embodiment. FIG. **9** is an example of a configuration in which the battery **30** mounted in the vehicle **1** is a combination of two batteries **30** (a battery **30***a* and a battery **30***b*). In (a) of FIG. **9**, a connection of the AC generation circuit **42-1** (an AC generation circuit **42-1***a* and an AC generation circuit **42-1***b*) corresponding to each battery **30** and an AC current flowing into each AC generation circuit **42-1** are shown. In (b) of FIG. **9**, an example of control signals output to the switches by the controller **44** and an AC current and an output voltage within each AC generation circuit **42-1** is shown. In FIG. **9**, “a” added to the end of each reference sign indicates that it corresponds to the AC generation circuit **42-1***a*, and “b” added to the end of each reference sign indicates that it corresponds to the AC generation circuit **42-1***b*.

(87) As shown in (a) of FIG. **9**, in the case of a configuration in which two batteries **30** are combined, the AC generation circuit **42-1***a* is connected to one battery **30***a* and the AC generation circuit **42-1***b* is connected to the other battery **30***b*. The controller **44** outputs a control signal to the switch provided in each AC generation circuit **42-1** such that the phase of the AC current generated by each AC generation circuit **42-1** is shifted by 180°. In (b) of FIG. **9**, a case in which the controller **44** outputs a control signal having a duty ratio of 50% to each AC generation circuit **42-1** such that each AC generation circuit **42-1** is allowed to generate an AC current of a sinusoidal wave is shown. The control signal shown in (b) of FIG. **9** is also an example of a control signal when the controller **44** controls each switch without providing a dead time.

(88) In (a) of FIG. **9**, an example of a voltage measurement position and a current flow direction that change in each AC generation circuit **42-1** when the controller **44** controls each switch using a control signal is shown. More specifically, a voltage V**1**-V**0** between both electrodes of the battery **30***a* (including inductance Laa), a current I-C**1***a* flowing through a capacitor C**1***a*, a current I-C**2***a* flowing through a capacitor C**2***a* and a current I-E**1***a* flowing through the battery **30***a* (including the inductance Laa) are shown as an example of the voltage and current corresponding to the AC generation circuit **42-1***a*. Further, a voltage V**2**-V**1** between both electrodes of the battery **30***b* (including inductance Lab), a current I-C**1***b* flowing through a capacitor C**1***b*, a current I-C**2***b* flowing through a capacitor C**2***b* and a current I-E**1***b* flowing through the battery **30***b* (including the inductance Lab) are shown as an example of the voltage and current corresponding to the AC generation circuit **42-1***b*. In (a) of FIG. **9**, a voltage V**2**-V**0** between both ends of one end (V**0**) on the negative electrode side of the battery **30***a* in the AC generation circuit **42-1***a* and one end (V**2**) on the positive electrode side of the battery **30***b* in the AC generation circuit **42-1***b* is shown as the entire voltage of the combination of the battery **30***a* and the battery **30***b*. In (b) of FIG. **9**, an example of changes in the current and voltage between the AC generation circuit **42-1***a* and the AC generation circuit **42-1***b* is shown.

(89) As shown in (b) of FIG. **9**, during the period P**1**, the controller **44** sets the control signal CS**1***a* and the control signal CS**2***a* of the AC generation circuit **42-1***a* at the “Low” level and sets the control signal CS**3***a* at the “High” level. Thereby, in the AC generation circuit **42-1***a*, the capacitor C**1***a* and the capacitor C**2***a* are connected in series via the inductor L**3***a* and the current I-C**1***a* and the current I-C**2***a* mainly flow in the negative region as in the series connection period PS shown in (b) of FIG. **8**, such that the current I-E**1***a* also flows mainly in the negative region. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-1***a* rises from the negative peak voltage to the positive peak voltage, as in the series connection period PS shown in (b) of FIG. **8**. On the other hand, during the period P**1**, the controller **44** sets the control signal CS**1***b* and the control signal CS**2***b* of the AC generation circuit **42-1***b* at the “High” level and sets the control signal CS**3***b* at the “Low” level. Thereby, in the AC generation circuit **42-1***b*, the capacitor C**1***b* and the capacitor C**2***b* are connected in parallel and the current I-C**1***b* and the current I-C**2***b* flow mainly in the positive region as in the parallel connection period PP shown in (b) of FIG. **8**, such that the current I-E**1***b* also flows mainly in the positive region. Thereby, the voltage V**2**-V**1** of the AC generation circuit **42-1***b* drops from the positive peak voltage to the negative peak voltage.
(90) Subsequently, as shown in (b) of FIG. **9**, during the period P**2**, the controller **44** sets the control signal CS**1***a* and the control signal CS**2***a* of the AC generation circuit **42-1***a* at the “High” level and sets the control signal CS**3***a* at the “Low” level. Thereby, in the AC generation circuit **42-1***a*, the capacitor C**1***a* and the capacitor C**2***a* are connected in parallel and the current I-C**1***a* and the current I-C**2***a* mainly flow in the positive region as in the parallel connection period PP shown in (b) of FIG. **8**, such that the current I-E**1***a* also flows mainly in the positive region. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-1***a* drops from the positive peak voltage to the negative peak voltage. On the other hand, during the period P**2**, the controller **44** sets the control signal CS**1***b* and the control signal CS**2***b* of the AC generation circuit **42-1***b* at the “Low” level and sets the control signal CS**3***b* at the “High” level. Thereby, in the AC generation circuit **42-1***b*, the capacitor C**1***b* and the capacitor C**2***b* are connected in series via the inductor L**3***b* and the current I-C**1***b* and the current I-C**2***b* flow mainly in the negative region as in the series connection period PS shown in (b) of FIG. **8**, such that the current I-E**1***b* also flows mainly in the negative region. Thereby, the voltage V**2**-V**1** of the AC generation circuit **42-1***b* rises from the negative peak voltage to the positive peak voltage, as in the series connection period PS shown in (b) of FIG. **8**.
(91) As described above, when the battery **30** mounted in the vehicle **1** has a configuration in which two batteries **30** (here, the battery **30***a* and the battery **30***b*) are combined, the controller **44** controls the AC generation circuit **42-1** corresponding to each battery **30** by outputting a control signal such that the operation is reversed. Thereby, as shown in (b) of FIG. **9**, it is possible to reduce the change in the entire voltage V**2**-V**0** when the two batteries **30** are combined. This is because the current waveform of the AC current generated by each AC generation circuit **42-1** becomes a current waveform close to a sinusoidal wave that is symmetric between the positive current value and the negative current value.
Another Operation of Temperature Raising Device in Comparative Example
(92) Even in the AC generation circuit **42**-C of the comparative example shown in FIG. **4**, it is possible to apply the battery **30** mounted in the vehicle **1** to a configuration in which two batteries **30** are combined. However, because the current waveform of the alternating current generated by the AC generation circuit **42**-C is an asymmetric current waveform between the positive current value and the negative current value, the effect of reducing the change in the entire voltage when the two batteries **30** are combined is reduced.
(93) Here, an example of a case where the AC generation circuit **42**-C is applied to a configuration in which two batteries **30** are combined is shown for the comparison with the AC generation circuit **42-1**. FIG. **10** is a diagram showing another example of the operation waveform of the AC generation circuit **42**-C of the comparative example. FIG. **10** shows an example in which the AC generation circuit **42**-C is connected to each battery **30** when the battery **30** mounted in the vehicle

1 has a configuration in which two batteries **30** (the battery **30**_a_ and the battery **30**_b_) are combined. In this case, the operation of the AC generation circuit **42**-C and the control of the AC generation circuit **42**-C in the controller **44** are conceivable like the operation of the AC generation circuit **42-1** shown in FIG. **9** and the control of the AC generation circuit **42-1** in the controller **44** with reference to the operation of the AC generation circuit **42**-C shown in FIG. **6** or **7** and the control of the AC generation circuit **42**-C in the controller **44**. Accordingly, a detailed description related to the operation of the AC generation circuit **42**-C shown in FIG. **10** and the control of the AC generation circuit **42**-C in the controller **44** will be omitted.
(94) When the voltage waveform of the voltage V**2**-V**0** shown in (b) of FIG. **9** is compared with the voltage waveform of the voltage V**2**-V**0** shown in (b) of FIG. **10**, it can be seen that the effect of reducing the change in the voltage V**2**-V**0** is significant in the case where the AC generation circuit **42-1** is applied to the configuration in which the two batteries **30** are combined as compared with the case where the AC generation circuit **42**-C is applied to the configuration in which the two batteries **30** are combined.
(95) In this way, in the temperature raising device **40** of the first embodiment, the inductor L**3** having the inductance Ly having a value, which is one-third of the inductance component Ls of the inductance La provided in the battery **30**, is connected in parallel between the first terminal and the second terminal of the switch S**3** in the AC generation circuit **42-1**. In the temperature raising device **40** of the first embodiment, when an AC current based on electric power stored in the battery **30** is generated according to the resonance operation of the inductance La provided in the battery **30** and at least the capacitor C**1**, the inductor L**3** is arranged between the capacitor C**1** and the capacitor C**2** in the case where the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-1**. Thereby, in the temperature raising device **40** of the first embodiment, the current waveform of the generated AC current is made closer to a sinusoidal wave, the duty ratio of the control signal output by the controller **44** is made closer to 50%, and the controller **44** can easily control each switch. Thereby, in the temperature raising device **40** of the first embodiment, the temperature of the battery **30** can be raised more efficiently due to the AC current having a current waveform close to the sinusoidal wave generated by the AC generation circuit **42-1**.
(96) Further, in the temperature raising device **40** of the first embodiment, for example, when the battery **30** mounted in the vehicle **1** has a configuration in which two batteries **30** are combined, the controller **44** can reduce the change in the entire voltage output by a combination of the two batteries **30** by performing a control process in which a phase of the AC current generated by each AC generation circuit **42-1** is shifted (shifted by 180°).
Second Embodiment
(97) [Configuration of AC Generation Circuit Provided in Temperature Raising Device]
(98) FIG. **11** is a diagram showing an example of a configuration of an AC generation circuit **42** (hereinafter referred to as an "AC generation circuit **42-2**") provided in the temperature raising device **40** according to a second embodiment. In FIG. **11**, a battery **30** related to the AC generation circuit **42-2** is also shown. The AC generation circuit **42-2** includes, for example, a capacitor C**1**, a capacitor C**2**, a switch S**1**, a switch S**2**, a switch S**31**, a switch S**32**, an inductor L**3**, an inductor L**10**, and an inductor L**20**.
(99) The AC generation circuit **42-2** has a configuration in which two switches of the switch S**31** and the switch S**32** are replaced with the switch S**3** provided in the AC generation circuit **42-1** of the first embodiment and the inductor L**10** and the inductor L**20** are added. The other components provided in the AC generation circuit **42-2**, i.e., the capacitor C**1**, the capacitor C**2**, the switch S**1**, the switch S**2**, and the inductor L**3** are equivalent to those of the AC generation circuit **42-1** of the first embodiment. The inductor L**10** and the inductor L**20** are inductors having the same inductance. Like the switch S**3** provided in the AC generation circuit **42-1**, each of the switch S**31** and the switch S**32** is controlled in a conductive state (a closed state) in which a connection

between both terminals is established or a non-conductive state (an open state) in which the connection between both terminals is disconnected in accordance with a control signal output by the controller **44**. In the following description, the control signal output by the controller **44** to control the switch S**31** such that the switch S**31** is in the conductive state or the non-conductive state is referred to as a "control signal CS**31**" and the control signal output by the controller **44** to control the switch S**32** such that the switch S**32** is in the conductive state or the non-conductive state is referred to as a "control signal CS**32**." Like the switch S**3** provided in the AC generation circuit **42-1**, each of the switch S**31** and the switch S**32** may be a semiconductor switching element such as an N-channel type metal oxide film semiconductor field effect transistor (MOSFET).
(100) Even in the AC generation circuit **42-2**, a first end of the capacitor C**1** is connected to a positive electrode side of the battery **30** and a first end of the capacitor C**2** is connected to a negative electrode side of the battery **30**. Further, even in the AC generation circuit **42-2**, a first terminal of the switch S**2** is connected to the first end of the capacitor C**1** and a second terminal of the switch S**1** is connected to the first end of the capacitor C**2**. In the AC generation circuit **42-2**, a second terminal of the switch S**31**, a second end of the inductor L**3**, and a second end of the inductor L**20** are connected to a second end of the capacitor C**1**, and a first terminal of the switch S**32**, a first end of the inductor L**3**, and a first end of the inductor L**10** are connected to a second end of the capacitor C**2**. Further, in the AC generation circuit **42-2**, a first end of the inductor L**20** is connected between a first terminal of the switch S**1** and a second terminal of the switch S**32** and a second end of the inductor L**10** is connected between a second terminal of the switch S**2** and a first terminal of the switch S**31**.
(101) According to such a configuration, in the AC generation circuit **42-2**, the capacitor C**1** and the capacitor C**2** are connected in parallel or in series between the positive electrode side and the negative electrode side of the battery **30** in accordance with the control from the controller **44**. More specifically, the controller **44** allows the capacitor C**1** and the capacitor C**2** to be connected in parallel between the positive electrode side and the negative electrode side of the battery **30** by outputting a control signal CS**1** for setting the conductive state to the switch S**1**, outputting a control signal CS**2** for setting the conductive state to the switch S**2**, outputting a control signal CS**31** for setting the non-conductive state to the switch S**31**, and outputting a control signal CS**32** for setting the non-conductive state to the switch S**32**. On the other hand, the controller **44** allows the capacitor C**1** and the capacitor C**2** to be connected in series between the positive electrode side and the negative electrode side of the battery **30** by outputting the control signal CS**1** for setting the non-conductive state to the switch S**1**, outputting the control signal CS**2** for setting the non-conductive state to the switch S**2**, outputting the control signal CS**31** for setting the conductive state to the switch S**31**, and outputting the control signal CS**32** for setting the conductive state to the switch S**32**.
(102) In the AC generation circuit **42-2**, the capacitor C**1** is an example of a "first capacitor" in the claims and the capacitor C**2** is an example of a "second capacitor" in the claims. In the AC generation circuit **42-2**, a configuration in which the switch S**1** and the switch S**2** are combined is an example of a "parallel switch unit" in the claims and a configuration in which the switch S**31** and the switch S**32** are combined is an example of a "series switch unit" in the claims. In the AC generation circuit **42-2**, the switch S**1** is an example of a "first switch" in the claims, the switch S**2** is an example of a "second switch" in the claims, the switch S**31** is an example of a "third switch" in the claims, and switch S**32** is an example of a "fourth switch" in the claims. In the AC generation circuit **42-2**, the inductor L**3** is an example of a "first inductor" in the claims, the inductor L**10** is an example of a "second inductor" in the claims, and the inductor L**20** is an example of a "third inductor" in the claims. The control signal CS**1** output to the switch S**1** by the controller **44** and the control signal CS**2** output to the switch S**2** by the controller **44** are examples of a "first control signal" in the claims and the control signal CS**31** output to the switch S**31** by the controller **44** and the control signal CS**32** output to the switch S**32** by the controller **44** are examples of a "second

control signal" in the claims. In the AC generation circuit **42-2**, a state in which the capacitor C**1** and the capacitor C**2** are connected in parallel between the positive electrode side and the negative electrode side of the battery **30** is an example of a "first state" in the claims and a state in which the capacitor C**1** and the capacitor C**2** are connected in series between the positive electrode side and the negative electrode side of the battery **30** is an example of a "second state" in the claims.
(103) [Operation of Temperature Raising Device]
(104) FIG. **12** is an example of a circuit equivalent to the AC generation circuit **42-2** of the second embodiment. An equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected in series to the battery **30** is shown in (a) of FIG. **12** and an equivalent circuit when the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel is shown in (b) of FIG. **12**. Even in FIG. **12**, an inductance component of the inductance La provided in the battery **30** is denoted by "Ls" and a resistance component of the resistance Ra is denoted by "Rs." The capacitance of the capacitors C**1** and C**2** is denoted by "Cx," and the inductance of the inductor L**3** is denoted by "Ly." Further, the inductance of the inductor L**10** and the inductor L**20** is denoted by "Lx."
(105) Because the capacitor C**1** and the capacitor C**2** are capacitors having the same capacitance, the total capacitance is different between a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series and a case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel even in the AC generation circuit **42-2** as in the AC generation circuit **42-1** when the capacitor C**1** and the capacitor C**2** are considered to be one capacitor. Thus, the frequency of a generated AC current is different between the case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in series and the case where the capacitor C**1** and the capacitor C**2** are connected to the battery **30** in parallel even in the AC generation circuit **42-2** as in the AC generation circuit **42-1**. Even in the AC generation circuit **42-2**, preferably, a current waveform of the generated AC current is a sinusoidal wave and the duty ratio of each of the control signals output by the controller **44** to the switch S**1**, the switch S**2**, the switch S**31**, and the switch S**32** is 50% such that the temperature of the battery **30** is efficiently raised by the temperature raising device **40**. Here, the frequency of the AC current generated by the AC generation circuit **42-2** is considered.
(106) First, a resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in series shown in (a) of FIG. **12** will be described. When the capacitor C**1** and the capacitor C**2** are connected in series in the AC generation circuit **42-2**, a circuit of the inductor L**3**, the inductor L**10**, and the inductor L**20** is arranged between the capacitor C**1** and the capacitor C**2**. Thus, the impedance Z when the capacitor C**1** and the capacitor C**2** are connected in series in the AC generation circuit **42-2** can be obtained as shown in the following Eq. (11).

(107)
$$\begin{aligned} Z &= \mathrm{ZLs} + 2\mathrm{ZCx} + \frac{1}{\frac{2}{\mathrm{ZLx}} + \frac{1}{\mathrm{ZLy}}} + \mathrm{Rs} = \mathrm{ZLs} + 2\mathrm{ZCx} + \frac{\mathrm{ZLx}\ .\mathrm{Math.}\ \mathrm{ZLy}}{\mathrm{ZLx} + 2\mathrm{ZLy}} + \mathrm{Rs} \\ &= \frac{2\mathrm{ZCx}(\mathrm{ZLx} + 2\mathrm{ZLy}) + \mathrm{ZLs}(\mathrm{ZLx} + 2\mathrm{ZLy}) + \mathrm{ZLx}\ .\mathrm{Math.}\ \mathrm{ZLy}}{\mathrm{ZLx} + 2\mathrm{ZLy}} + \mathrm{Rs} \\ &= \frac{\frac{2}{J\omega\mathrm{Cx}}(j\omega\mathrm{Lx} + 2j\omega\mathrm{Ly}) + j\omega\mathrm{Ls}(j\omega\mathrm{Lx} + 2j\omega\mathrm{Ly}) + j\omega\mathrm{Lx}\ .\mathrm{Math.}\ j\omega\mathrm{Ly}}{j\omega\mathrm{Lx} + 2j\omega\mathrm{Ly}} + \mathrm{Rs} \\ &= \frac{\frac{2\mathrm{Lx} + 4\mathrm{Ly}}{\mathrm{Cx}} - \omega^2(\mathrm{Ls}\ .\mathrm{Math.}\ \mathrm{Lx} + 2\mathrm{Ls}\ .\mathrm{Math.}\ \mathrm{Ly} + \mathrm{Lx}\ .\mathrm{Math.}\ \mathrm{Ly})}{j\omega\mathrm{Lx} + 2j\omega\mathrm{Ly}} + \mathrm{Rs} \end{aligned} \quad (11)$$

(108) A resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series in the AC generation circuit **42-2** is the frequency at which the impedance Z obtained by the above Eq. (11) becomes the minimum and which becomes equal to that of the resistance component Rs. From this, it is only necessary to set the numerator portion of a first term on the right side in the above Eq. (11) to zero for the resonance frequency cos. That is, it is only necessary to set the resonance frequency cos such that the following Eq. (12) is established.
(109) 0 $\frac{2\mathrm{Lx} + 4\mathrm{Ly}}{\mathrm{Cx}} - \omega s^2(\mathrm{Ls}\ .\mathrm{Math.}\ \mathrm{Lx} + 2\mathrm{Ls}\ .\mathrm{Math.}\ \mathrm{Ly} + \mathrm{Lx}\ .\mathrm{Math.}\ \mathrm{Ly}) = 0$ (12)
(110) From the above Eq. (12), the resonance frequency cos can be obtained as in the following Eq.

(13).

(111) $\omega s = \sqrt{\frac{2Lx + 4Ly}{Cx(Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly)}}$ (13)

(112) Next, the resonance frequency when the capacitor C**1** and the capacitor C**2** are connected in parallel shown in (a) of FIG. **12** will be described. When the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-2**, the inductor L**10** is connected in series between the first end of the capacitor C**1** and the second end of the capacitor C**2**, the inductor L**20** is connected in series between the second end of the capacitor C**1** and the first end of the capacitor C**2**, and the inductor L**3** is connected between the inductor L**10** and the inductor L**20**. Thus, the impedance Z when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-2** can be obtained as shown in the following Eq. (14).

(113)
$$
\begin{aligned}
Z &= ZLs + \frac{2ZCx \cdot ZLx + ZCx \cdot ZLy + ZLx \cdot ZLy}{ZCx + ZLx + 2ZLy} + Rs \\
&= \frac{ZLs(ZCx + ZLx + 2ZLy) + 2ZCx \cdot ZLx + ZCx \cdot ZLy + ZLx \cdot ZLy}{ZCx + ZLx + 2ZLy} + Rs \\
&= \frac{j\omega Ls(\frac{1}{j\omega Cx} + j\omega Lx + 2j\omega Ly) + \frac{2}{j\omega Cx} \cdot j\omega Lx + \frac{1}{j\omega Cx} \cdot j\omega Ly + j\omega Lx \cdot j\omega Ly}{\frac{1}{j\omega Cx} + j\omega Lx + 2j\omega Ly} + Rs \\
&= \frac{Ls(\frac{1}{Cx} - \omega^2 Lx - 2\omega^2 Ly) + \frac{2Lx}{Cx} + \frac{Ly}{Cx} - \omega^2 Lx \cdot Ly}{\frac{1}{j\omega Cx} + j\omega Lx + 2j\omega Ly} + Rs \\
&= \frac{\frac{Ls + 2Lx + Ly}{Cx} - \omega^2 (Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly)}{\frac{1}{j\omega Cx} + j\omega Lx + 2j\omega Ly} + Rs
\end{aligned}
\tag{14}
$$

(114) Here, the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel in the AC generation circuit **42-2** is a frequency at which the impedance Z obtained by the above Eq. (14) becomes the minimum and which becomes equal to that of the resistance component Rs. From this, it is only necessary to set the numerator portion of a first term on the right side in the above Eq. (14) to zero for the resonance frequency top. That is, it is only necessary to set the resonance frequency top such that the following Eq. (15) is established.

(115) $\frac{Ls + 2Lx + Ly}{Cx} - \omega p^2 (Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly) = 0$ (15)

(116) From the above Eq. (15), the resonance frequency top can be obtained as in the following Eq. (16).

(117) $\omega p = \sqrt{\frac{Ls + 2Lx + Ly}{Cx(Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly)}}$ (16)

(118) Here, when the resonance frequency cos and the resonance frequency top are compared, the resonance frequency cos can be expressed as the following Eq. (17) and the resonance frequency top can be expressed as the following Eq. (18).

(119) $\omega s^2 = \frac{2Lx + 4Ly}{Cx(Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly)}$ (17)

$\omega p^2 = \frac{Ls + 2Lx + Ly}{Cx(Ls \cdot Lx + 2Ls \cdot Ly + Lx \cdot Ly)}$ (18)

(120) From this, in the AC generation circuit **42-2**, it is only necessary to establish the following Eq. (19) such that the resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series is equal to the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel.

$2Lx+4Ly=Ls+2Lx+Ly$

$3Ly=Ls$ (19)

(121) From this, it is only necessary to set the inductance Ly of the inductor L**3** in the AC generation circuit **42-2** such that the following Eq. (20) is established.

(122) $Ly = \frac{Ls}{3}$ (20)

(123) This is the same as that of the AC generation circuit **42-1** of the first embodiment. That is,

even in the AC generation circuit **42-2**, if the inductance Ly of the inductor L**3** is set to one-third of the inductance component Ls of the inductance La provided in the battery **30**, the resonance frequency cos when the capacitor C**1** and the capacitor C**2** are connected in series can be equal to the resonance frequency top when the capacitor C**1** and the capacitor C**2** are connected in parallel. Thereby, the capacitor C**1** and the capacitor C**2** are connected in series or in parallel even in the AC generation circuit **42-2**, such that the current waveform of the generated AC current is made closer to a sinusoidal wave, the duty ratio of the control signal output by the controller **44** is made close to 50%, and the controller **44** can easily control each switch.

(124) FIG. **13** is a diagram showing an example of an operation waveform (a simulation waveform) of the AC generation circuit **42-2** of the second embodiment. Even in FIG. **13**, control signals and a voltage and a current changed with the control signals are shown as in the example of the operation waveform of the AC generation circuit **42-1** shown in FIG. **8**. In (a) of FIG. **13**, an example of control signals output by the controller **44** and changes in a voltage V**1**-V**0** between both electrodes of the battery **30** (including the inductance La) and a current I-C**1**, a current I-C**2**, and a current I-E**1** flowing through the components, which change with the control signals, is shown. In (b) of FIG. **13**, an example of a measurement position of the voltage V**1**-V**0** and a direction in which each of the current I-C**1**, the current I-C**2**, and the current I-E**1** flows is shown.

(125) The operation waveform shown in (a) of FIG. **13** is also an example of a case where the controller **44** outputs a control signal having a duty ratio of 50% to each switch such that the AC generation circuit **42-2** is allowed to generate an AC current of a sinusoidal wave. As in the example of the operation waveform of the AC generation circuit **42-1** shown in FIG. **8**, the operation waveform shown in (a) of FIG. **13** is also an example of a case where the controller **44** controls each switch without providing a dead time.

(126) As shown in (a) of FIG. **13**, in the AC generation circuit **42-2**, the current I-E**1** also flows mainly in the negative region when the current I-C**1** and the current I-C**2** flow mainly in the negative region in a series connection period PS in which the controller **44** sets the control signal CS**1** and the control signal CS**2** at a “Low” level and sets the control signal CS**31** and the control signal CS**32** at a “High” level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-2** rises from a negative peak voltage to a positive peak voltage. On the other hand, in the AC generation circuit **42-2**, the current I-E**1** also flows mainly in the positive region when the current I-C**1** and the current I-C**2** flow mainly in the positive region in a parallel connection period PP in which the controller **44** sets the control signal CS**1** and the control signal CS**2** at the “High” level and sets the control signal CS**31** and the control signal CS**32** at the “Low” level. Thereby, the voltage V**1**-V**0** of the AC generation circuit **42-2** drops from the positive peak voltage to the negative peak voltage.

(127) In this way, even in the AC generation circuit **42-2**, as in the AC generation circuit **42-1**, the controller **44** can output a control signal to each switch and switch the connection of the capacitor C**1** and the capacitor C**2** to the battery **30** to a series connection or a parallel connection, such that an AC current can be generated. Moreover, as can be seen from the waveforms of the current I-E**1** and the voltage V**1**-V**0** in each of the series connection period PS and the parallel connection period PP shown in (a) of FIG. **13**, the current waveform of the AC current generated by the AC generation circuit **42-2** is closer to a sinusoidal wave than the AC current waveform generated by the AC generation circuit **42-1** shown in (a) of FIG. **8** and the amplitude thereof also has a smaller absolute value difference between the positive region and the negative region of the AC current.

(128) In this way, even in the configuration of the AC generation circuit **42-2**, as in the AC generation circuit **42-1**, the duty ratio of the control signal output by the controller **44** can be set to 50% and the current waveform of the generated AC current can be made closer to a sinusoidal wave. Thereby, even in the AC generation circuit **42-2**, as in the AC generation circuit **42-1**, it is possible to facilitate the control of each switch in the controller **44** and raise the temperature of the battery **30** more efficiently according to the generated AC current of the current waveform close to the sinusoidal wave. In the AC generation circuit **42-2**, it is possible to further reduce the noise

radiated when the temperature of the battery **30** is raised by generating an AC current closer to a sinusoidal wave, i.e., an AC current obtained by further reducing the number of harmonic components.

(129) [Another Operation of Temperature Raising Device]

(130) Like the AC generation circuit **42-1**, the AC generation circuit **42-2** can also be applied to a configuration in which a plurality of (for example, two) batteries **30** mounted in the vehicle **1** are combined. FIG. **14** is a diagram showing another example of an operation waveform (a simulation waveform) of the AC generation circuit **42-2** of the second embodiment. FIG. **14** is also an example of a case where the AC generation circuit **42-2** is connected to each battery **30** in a configuration in which the battery **30** mounted in the vehicle **1** is a combination of two batteries **30** (the battery **30***a* and the battery **30***b*) as in another example of the operation waveform of the AC generation circuit **42-1** shown in FIG. **9**. Even in (a) of FIG. **14**, a connection of the AC generation circuit **42-2** (an AC generation circuit **42-2***a* and an AC generation circuit **42-2***b*) corresponding to each battery **30** and the AC current flowing into each AC generation circuit **42-2** are shown. Even in (b) of FIG. **14**, an example of changes in the control signals output to the switches by the controller **44**, the AC current within each AC generation circuit **42-2**, and the output voltage is shown.

(131) As shown in (a) of FIG. **14**, in the case of a configuration in which two batteries **30** are combined, the AC generation circuit **42-2***a* is connected to the battery **30***a* and the AC generation circuit **42-2***b* is connected to the battery **30***b*. The controller **44** outputs a control signal to the switch provided in each AC generation circuit **42-2** such that the phase of the AC current generated by each AC generation circuit **42-2** is shifted by 180°. Even in (b) of FIG. **14**, a case where the controller **44** outputs a control signal of a duty ratio of 50% to each AC generation circuit **42-2** such that each AC generation circuit **42-2** is allowed to generate an AC current of a sinusoidal wave is shown. The control signal shown in (b) of FIG. **14** is also an example of a control signal when the controller **44** controls each switch without providing a dead time.

(132) In this case, the operation of the AC generation circuit **42-2** and the control of the AC generation circuit **42-2** in the controller **44** are considered to be similar to the operation of the AC generation circuit **42-1** shown in FIG. **9** and the control of the AC generation circuit **42-1** in the controller **44** with reference to the operation of the AC generation circuit **42-2** shown in FIG. **13** and the control of the AC generation circuit **42-2** in the controller **44**. Accordingly, detailed description of the operation of the AC generation circuit **42-2** shown in FIG. **14** and the control of the AC generation circuit **42-2** in the controller **44** will be omitted.

(133) When the voltage waveform of the voltage V**2**-V**0** shown in (b) of FIG. **14** is compared with the voltage waveform of the voltage V**2**-V**0** shown in (b) of FIG. **9**, it can be seen that a voltage change in the voltage V**2**-V**0** is reduced in a case where the AC generation circuit **42-2** is applied to the configuration in which the two batteries **30** are combined as compared with the case where the AC generation circuit **42-1** is applied to the configuration in which the two batteries **30** are combined.

(134) As described above, in the temperature raising device **40** of the second embodiment, the AC generation circuit **42-2** includes the inductor L**3** having the inductance Ly, which is one-third of the inductance component Ls of the inductance La provided in the battery **30**, and the inductor L**10** and the inductor L**20** having the same inductance Lx. In the temperature raising device **40** of the second embodiment, when the AC current based on the electric power stored in the battery **30** is generated according to the resonance operation of the inductance La provided in the battery **30** and at least the capacitor C**1**, a circuit of the inductor L**3**, the inductor L**10**, and the inductor L**20** arranged between the capacitor C**1** and the capacitor C**2** is different between the case where the capacitor C**1** and the capacitor C**2** are connected in series and the case where the capacitor C**1** and the capacitor C**2** are connected in parallel. Thereby, in the temperature raising device **40** of the second embodiment, the current waveform of the generated AC current can be made closer to a sinusoidal

wave, the duty ratio of the control signal output by the controller **44** can be made close to 50%, and the controller **44** can easily control each switch. Thereby, in the temperature raising device **40** of the second embodiment, it is possible to raise the temperature of the battery **30** more efficiently according to an AC current of a current waveform closer to a sinusoidal wave generated by the AC generation circuit **42-2**.
(135) Further, even in the temperature raising device **40** of the second embodiment, for example, as in the temperature raising device **40** of the first embodiment, for example, when the battery **30** mounted in the vehicle **1** has a configuration in which two batteries **30** are combined, the controller **44** can reduce the change in the entire voltage output by a combination of the two batteries **30** by performing a control process in which a phase of the AC current generated by each AC generation circuit **42-1** is shifted (shifted by 180°).
(136) Here, differences between characteristics of AC currents generated by the AC generation circuit **42**-C of the comparative example, the AC generation circuit **42-1** of the first embodiment, and the AC generation circuit **42-2** of the second embodiment will be described. FIG. **15** is a diagram for comparing characteristics between the AC currents generated by the AC generation circuits **42** (the AC generation circuit **42**-C, the AC generation circuit **42-1**, and the AC generation circuit **42-2**). In (a) of FIG. **15**, characteristics of a ratio of harmonic components included in the current waveforms of the AC currents generated by the AC generation circuits **42** when a component of the fundamental wave of the AC current generated by each AC generation circuit **42** is normalized as “1” are shown. In (b) of FIG. **15**, characteristics of harmonic distortion in current waveforms of the AC currents generated by the AC generation circuits **42** are shown. In FIG. **15**, characteristics of AC currents of the current I-E**1** of the AC generation circuit **42**-C shown in FIG. **7**, the current I-E**1** of the AC generation circuit **42-1** shown in FIG. **8**, and the current I-E**1** of the AC generation circuit **42-2** shown in FIG. **13** are compared.
(137) As shown in (a) of FIG. **15**, a ratio of a “second harmonic,” a “third harmonic,” a “fourth harmonic,” and a “fifth harmonic” when the component of the fundamental wave is “1” is highest in the current I-E**1** generated by the AC generation circuit **42-**C and lower in the currents I-E**1** generated by the AC generation circuit **42-1** and the AC generation circuit **42-2**. In particular, in the AC generation circuit **42-1** and the AC generation circuit **42-2**, the third to the fifth harmonics are lower. Then, as shown in (b) of FIG. **15**, the harmonic distortion in the current waveform of the current I-E**1** generated by each AC generation circuit **42** is also greatest in the current I-E**1** generated by the AC generation circuit **42**-C and less in the order of the current I-E**1** generated by the AC generation circuit **42-1** and the current I-E**1** generated by the AC generation circuit **42-2**.
(138) From these facts, it can be seen that the current I-E**1** (the AC current) with the reduced number of harmonic components or the reduced harmonic distortion can be generated as compared with the AC generation circuit **42-**C in the AC generation circuit **42-1** and the AC generation circuit **42-2**. This is because the AC generation circuit **42-1** and the AC generation circuit **42-2** include the inductor L**3** and therefore the current waveform of the generated current I-E**1** (the AC current) becomes a current waveform closer to a sinusoidal wave. Further, it can be seen that the AC generation circuit **42-2** can generate the current I-E**1** (the AC current) having less harmonic distortion than the AC generation circuit **42-1**. This is because the AC generation circuit **42-2** further includes the inductor L**10** and the inductor L**20** and therefore the current waveform of the current I-E**1** (the AC current) generated thereby is closer to the sinusoidal wave than the current waveform of the current I-E**1** (the AC current) generated by the AC generation circuit **42-1**.
(139) As described above, according to the temperature raising device **40** of each embodiment, the AC generation circuit **42** includes an inductor L**3** having an inductance Ly that is one-third of the inductance component Ls of the inductance La provided in the battery **30**. In the temperature raising device **40** of each embodiment, an AC current based on electric power stored in the battery **30** is generated using a resonance operation of alternately exchanging magnetic energy stored in the inductance La provided in the battery **30** and at least electrostatic energy stored in the capacitor C**1**

by switching the connection of the capacitor C**1** and the capacitor C**2** provided in the AC generation circuit **42** to the battery **30** to the series connection or the parallel connection. At this time, in the temperature raising device **40** of each embodiment, at least when the capacitor C**1** and the capacitor C**2** provided in the AC generation circuit **42** are connected to the battery **30** in parallel, the inductor L**3** is arranged between the capacitor C**1** and the capacitor C**2**. Thereby, in the temperature raising device **40** of each embodiment, the current waveform of the AC current generated by the AC generation circuit **42** becomes a current waveform closer to a sinusoidal wave. Thereby, in the temperature raising device **40** of each embodiment, the temperature of the battery **30** can be raised more efficiently due to the AC current having a current waveform close to the sinusoidal wave generated by the AC generation circuit **42**. Thereby, in the vehicle **1** in which the temperature raising device **40** of each embodiment is adopted, the battery **30** can be used in a state in which the temperature of the battery **30** is raised to a suitable temperature and the deterioration of charging/discharging performance of the battery **30** can be limited. Further, in the vehicle **1** in which the temperature raising device **40** of each embodiment is adopted, because the number of harmonic components provided in the alternating current generated by the AC generation circuit **42** is small, the noise radiated when the temperature of the battery **30** is raised can be reduced.
(140) By the way, a case where the inductance Ly of the inductor L**3** provided in the AC generation circuit **42** (the AC generation circuit **42-1** or the AC generation circuit **42-2**) has a value which is one-third of the inductance component Ls of the inductance La provided in the battery **30** in the temperature raising device **40** of each of the above-described embodiments has been described. However, it is assumed that the inductance component Ls of the inductance La provided in the battery **30** has variations in characteristics even if the batteries **30** of the same type are used. Further, it is assumed that a wiring portion for connecting the AC generation circuit **42** and the battery **30** also includes an inductance component. Thus, in the temperature raising device **40** of each embodiment, the inductance Ly of the inductor L**3** provided in the AC generation circuit **42** has a value considering the variation of the inductance component Ls of the inductance La provided in the battery **30** and the inductance component included in the wiring portion for connecting the AC generation circuit **42** and the battery **30**. That is, in the temperature raising device **40** of each embodiment, the inductance Ly of the inductor L**3** may be set to a value having a certain width with respect to a value that is one-third of the inductance component Ls of the inductance La provided in the battery **30** within a range in which the current waveform of the AC current generated by the AC generation circuit **42** can be regarded as a sinusoidal wave (a range in which a substantial effect can be obtained). In other words, in the temperature raising device **40** of each embodiment, it is only necessary to set the inductance Ly of the inductor L**3** provided in the AC generation circuit **42** to a value of a range in which the inductance Ly can be set to one-third of the substantial inductance component Ls of the inductance La provided in the battery **30**, i.e., a range in which the inductance Ly can be set to approximately one-third of the substantial inductance component Ls of the inductance La provided in the battery **30**. For example, in the temperature raising device **40** of each embodiment, the inductance Ly of the inductor L**3** provided in the AC generation circuit **42** may be set to a value of a range having a width from one-fourth to two-fifths of the inductance component Ls of the inductance La provided in the battery **30**.
(141) In the temperature raising device **40** of each of the above-described embodiments, a case where the duty ratio of the control signal output to each switch by the controller **44** is 50% has been described. However, as described above, the controller **44** may control the switch by providing a dead time for setting all the switches in the non-conductive state between a period in which the switch is set in the conductive state and a period in which the switch is set in the non-conductive state. For example, in the temperature raising device **40** of each embodiment, the connection of the capacitor C**1** and the capacitor C**2** to the battery **30** may be switched from the parallel connection to the series connection or vice versa by setting the duty ratio of the control signal output to each switch to a value (for example, a prescribed value between 45% and 55% or the like) capable of

being regarded as approximately 50% and providing the dead time and outputting the control signal to each switch.

(142) According to the temperature raising device **40** of each of the above-described embodiments, the AC generation circuit **42** for raising the temperature of the battery **30** by generating an AC current based on electric power stored in the battery **30** having the inductance La includes the capacitor C**1** having a first end connected to a positive electrode side of the battery **30**; the capacitor C**2** having a first end connected to a negative electrode side of the battery **30**; a parallel switch unit configured to connect the capacitor C**1** and the capacitor C**2** to the battery **30** in parallel by connecting a second end of the capacitor C**1** and the first end of the capacitor C**2** and connecting the first end of the capacitor C**1** and a second end of the capacitor C**2** in accordance with a first control signal (for example, the control signal CS**1** and the control signal CS**2**); a series switch unit configured to connect the capacitor C**1** and the capacitor C**2** to the battery **30** in series by connecting the second end of the capacitor C**1** and the second end of the capacitor C**2** in accordance with a second control signal (for example, the control signal CS**3**); and the inductor L**3** connected between both terminals of the series switch unit, whereby it is possible to raise the temperature of the battery **30** for traveling mounted in the vehicle **1**. Thereby, in the vehicle **1** in which the temperature raising device **40** of each embodiment is adopted, the battery **30** can be used in a state in which the temperature of the battery **30** is raised to a suitable temperature and the deterioration of the charging/discharging performance of the battery **30** can be limited. Thereby, in the vehicle **1** equipped with the temperature raising device **40** of each embodiment, it is possible to improve the marketability of the vehicle **1** such as the improvement of durability. From these facts, the vehicle **1** equipped with the temperature raising device **40** of each embodiment is expected to contribute to improving energy efficiency and reducing adverse effects on the global environment.

(143) In each of the above-described embodiments, a configuration in which the control device **100** controls the activation or stopping of the temperature raising device **40** and the controller **44** controls each switch provided in the AC generation circuit **42** such that the switch is in the conductive state or the non-conductive state has been described. The operation of the controller **44** may be implemented when a hardware processor such as a CPU provided in the controller **44** executes a program. The function of the control device **100** may include the function of the controller **44** described above. In this case, the controller **44** may be omitted in the temperature raising device **40**.

(144) Although modes for carrying out the present invention have been described using embodiments, the present invention is not limited to the embodiments and various modifications and substitutions can also be made without departing from the scope and spirit of the present invention.

Claims

1. An alternating current (AC) generation circuit for raising a temperature of a power storage by generating an AC current based on electric power stored in the power storage having an inductance component, the AC generation circuit comprising: a first capacitor having a first end connected to a positive electrode side of the power storage; a second capacitor having a first end connected to a negative electrode side of the power storage; a parallel switch unit configured to connect the first capacitor and the second capacitor to the power storage in parallel by connecting a second end of the first capacitor and the first end of the second capacitor and connecting the first end of the first capacitor and a second end of the second capacitor in accordance with a first control signal; a series switch unit configured to connect the first capacitor and the second capacitor to the power storage in series by connecting the second end of the first capacitor and the second end of the second capacitor in accordance with a second control signal; and an inductor connected between both terminals of the series switch unit.

2. The AC generation circuit according to claim 1, wherein the parallel switch unit includes a first switch having a first terminal connected to the second end of the first capacitor and a second terminal connected to the first end of the second capacitor; and a second switch having a first terminal connected to the first end of the first capacitor and a second terminal connected to the second end of the second capacitor, wherein the series switch unit includes a third switch having a first terminal connected to the second end of the second capacitor and a second terminal connected to the second end of the first capacitor, and wherein the inductor is connected in parallel between the first terminal of the third switch and the second terminal of the third switch.
3. The AC generation circuit according to claim 2, wherein inductance of the inductor is approximately one-third of the inductance component.
4. The AC generation circuit according to claim 1, wherein the parallel switch unit includes a first switch having a first terminal connected to the second end of the first capacitor and a second terminal connected to the first end of the second capacitor; and a second switch having a first terminal connected to the first end of the first capacitor and a second terminal connected to the second end of the second capacitor, wherein the series switch unit includes a third switch having a first terminal connected to the second end of the second switch and a second terminal connected to the second end of the first capacitor; and a fourth switch having a first terminal connected to the second end of the second capacitor and a second terminal connected to the first terminal of the first switch, and wherein the inductor includes a first inductor having a first end connected to the first terminal of the fourth switch and a second end connected to the second terminal of the third switch; a second inductor having a first end connected to the first end of the first inductor and a second end connected between the second terminal of the second switch and the first terminal of the third switch; and a third inductor having a first end connected between the first terminal of the first switch and the second terminal of the fourth switch and a second end connected to the second end of the first inductor.
5. The AC generation circuit according to claim 4, wherein inductance of the first inductor is approximately one-third of the inductance component.
6. The AC generation circuit according to claim 5, wherein inductance of the second inductor is equal to inductance of the third inductor.
7. The AC generation circuit according to claim 1, wherein the inductance component includes an inductance component provided in a wiring portion between the power storage and the AC generation circuit.
8. A temperature raising device comprising: the AC generation circuit according to claim 1; and a controller configured to output a signal of a prescribed duty ratio for setting the parallel switch unit in a conductive state or a non-conductive state as the first control signal, output a signal of the prescribed duty ratio for setting the series switch unit in the conductive state or the non-conductive state as the second control signal, and alternately switch the state between a first state in which the parallel switch unit is in the conductive state and the series switch unit is in the non-conductive state and a second state in which the parallel switch unit is in the non-conductive state and the series switch unit is in the conductive state according to the first control signal and the second control signal.
9. The temperature raising device according to claim 8, wherein the prescribed duty ratio is approximately 50 percent.