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DUAL INVERTER SYSTEM

Abstract

The dual inverter system includes a first inverter connected to one end of a stator coil of the motor and a second inverter connected to the other end. The controller is capable of executing a single mode in which the second inverter is disconnected from the battery and the motor is driven only by the first inverter. When driving the motor in a single mode, the controller selects one of an upper short-circuiting circuit that turns on all the upper SW devices of the second inverter and turns off all the lower SW devices, and a lower short-circuiting circuit that turns on all the lower SW devices of the second inverter and turns off all the upper SW devices. The controllers compare the loads of the upper SW devices and the lower SW devices of the second inverters.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2024-022892 filed on Feb. 19, 2024, incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] The technology disclosed in the present specification relates to a dual inverter system that includes two inverters and one open winding motor.

2. Description of Related Art

[0003] Japanese Unexamined Patent Application Publication No. 2018-014829 (JP 2018-014829 A) discloses an example of a dual inverter system. In the dual inverter system, an alternating current end of a first inverter is connected to one end of a stator coil of a motor, and an alternating current end of a second inverter is connected to the other end of the stator coil. Turning switching devices of the first inverter and the second inverter on and off synchronously with each other enables a current that is twice as large as that when the motor is driven by one inverter to flow to the motor. That is to say, high torque is obtained at the motor. When high torque is not necessary, the other ends of a plurality of the stator coils are interconnected to create a neutral point, and the motor is driven by the first inverter alone. In the dual inverter system of JP 2018-014829 A, when the motor is driven only by the first inverter, a neutral point is created by holding all upper switching devices of the second inverter on, or by holding all lower switching devices of the second inverter on.

SUMMARY

[0004] In the dual inverter system of JP 2018-014829 A, when a neutral point is created in the second inverter, using only the upper switching devices, or using only the lower switching devices, will result in imbalance in cumulative loads of the upper switching devices and the lower switching devices. The present specification provides technology for evenly distributing load among upper switching devices and lower switching devices when creating a neutral point in a second inverter in a dual inverter system.

[0005] A dual inverter system disclosed in the present specification includes a first inverter, a second inverter, a motor, a linking switch, and a controller. A direct current end of the first inverter is connected to a battery, and each of a plurality of alternating current ends is connected to respective one ends of a plurality of stator coils of the motor. Each of a plurality of alternating current ends of the second inverter is connected to respective other ends of the stator coils. The linking switch connects a direct current end of the second inverter to the battery, and disconnects the direct current end of the second inverter from the battery, and so forth. The controller is configured to execute a dual mode in which the linking switch is closed and the motor is driven by the first inverter and the second inverter, and a single mode in which the linking switch is opened and the motor is driven by only the first inverter.

[0006] It is well known that an inverter includes a plurality of series circuits in which upper switching devices and lower switching devices are connected in series. The series circuits are connected in parallel between a positive electrode and a negative electrode of a direct current end of the inverter. A midpoint of each series circuit is connected to each of a plurality of alternating current ends of the inverter. When driving the motor in the single mode, the controller selects one of an upper short-circuiting circuit in which all upper switching devices of the second inverter are on and all lower switching devices are off, and a lower short-circuiting circuit in which all the lower switching devices of the second inverter are on and all the upper switching devices are off. The controller selects the upper short-circuiting circuit when a load of the upper switching devices of the second inverter is smaller than a load of the lower switching devices, and selects the lower

short-circuiting circuit when the load of the upper switching devices of the second inverter is greater than the load of the lower switching devices. In the dual inverter system disclosed in the present specification, when the motor is driven in the single mode, the switching devices of which the load is small are turned on to create a neutral point. Therefore, the load is evenly distributed among the upper switching devices and the lower switching devices.
[0007] The controller may identify the load of the switching devices based on at least one of a temperature, a driving time, and a count of times of driving, of the switching devices. Details of the technology disclosed in the present specification, and further improvements, are described in the "DETAILED DESCRIPTION OF EMBODIMENTS" below.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:
[0009] FIG. **1** is a circuit diagram of a dual inverter system according to an embodiment;
[0010] FIG. **2** is a circuit diagram showing current flow when an upper short-circuiting circuit is selected; and
[0011] FIG. **3** is a circuit diagram illustrating a current flow when a lower short-circuiting circuit is selected.
DETAILED DESCRIPTION OF EMBODIMENTS
[0012] A dual inverter system **2** according to an embodiment will be described with reference to the drawings. Hereinafter, for convenience of explanation, "dual inverter system" may be abbreviated as "DI system". FIG. **1** is a schematic diagram of a DI device **2**. DI device **2** includes a battery **3**, a first inverter **10**, a second inverter **20**, a motor **30**, a linking switch **40***p*, **40***n*, and controllers **50**. DI device **2** is mounted on, for example, a battery electric vehicle, and a motor **30** drives an axle.
[0013] The first inverter **10** includes a direct current terminal (positive electrode **10***p* and negative electrode **10***n*) and alternating current terminals **10***u*, **10***v*, **10***w*. The direct current end is connected to the battery **3**, and the alternating current end is connected to the motor **30**.
[0014] The first inverter **10** includes three sets of series-circuit **11***u*, **11***v*, **11***w*. The series circuit **11***u* includes a series-connected circuit of the upper switching device **12***u* and the lower switching device **13***u*. Hereinafter, for convenience of explanation, the "switching device" may be abbreviated as a SW device. The upper SW device **12** and the lower SW device **13** are connected in anti-parallel. The hardware of the diode may be a separate device from SW device or may be incorporated in SW device.
[0015] The series-circuit **11***u* is connected between the positive electrode **10***p* and the negative electrode **10***n* of the direct current terminal of the first inverter **10**. The upper SW device **12***u* is connected to the positive electrode **10***p*, and the lower SW device **13***u* is connected to the negative electrode **10***n*. The midpoint of the series circuit **11***u*, that is, the midpoint of the series-connected circuit of the upper SW device **12***u* and the lower SW device **13***u* is connected to the alternating current terminal **10***u* of the first inverter **10**.
[0016] The series circuit **11***v* is composed of a series-connected circuit of an upper SW device **12***v* and a lower SW device **13***v*. The series circuit **11***w* is composed of a series-connected circuit of an upper SW device **12***w* and a lower SW device **13***w*. The series circuit **11***v*, **11***w* has the same construction as the series circuit **11***u*. Hereinafter, the upper SW device **12***u*, **12***v*, **12***w* may be collectively referred to as the upper SW device **12**, and the lower SW devices **13***u*, **13***v*, **13***w* may be collectively referred to as the lower SW device **13**.
[0017] Each of the plurality of upper SW devices **12** is associated with a temperature sensor **14**,

and each of the plurality of lower SW devices **13** is associated with a temperature sensor **15**.
[0018] The upper SW device **12** and the lower SW device **13** are driven by the controllers **50**. When the controllers **50** alternately turn on and off the upper SW device **12** and the lower SW device **13** at a predetermined duty cycle, an alternating current flows through each of the alternating current terminals **10***u*, **10***v*, **10***w*.
[0019] For convenience of explanation, three sets of series circuit **11***u*, **11***v*, **11***w* may be collectively referred to as a series circuit **11**. Three series circuits **11** are connected in parallel between the positive electrode **10***p* and the negative electrode **10***n* of the direct current terminal of the first inverter **10**. A midpoint of each of the three sets of series circuits **11** is connected to each of the alternating current terminals **10***u*, **10***v*, **10***w*. When the controllers **50** appropriately drive the six SW devices of the first inverter **10**, an alternating current flows through each of the three alternating current terminals **10***u*, **10***v*, **10***w*.
[0020] The second inverter **20** has the same configuration as the first inverter **10**, and includes three series-circuit **21***u*, **21***v*, **21***w*. The second inverter **20** also uses a generic name similar to that of the first inverter **10**. For example, three sets of series circuit **21***u*, **21***v*, **21***w* are collectively referred to below as series circuits **21**. The same generic term is used for the upper SW devices **22***u*, **22***v*, **22***w* and the lower SW devices **23***u*, **23***v*, **23***w*.
[0021] Three series circuits **21** are connected in parallel between the positive electrode **20***p* and the negative electrode **20***n* of the direct current terminal of the second inverter **20**. Each of the series circuits **21** includes a series-connected circuit including an upper SW device **22** and a lower SW device **23**. The upper SW device **22** and the lower SW device **23** are connected in anti-parallel. The upper SW device **22** is connected to the positive electrode **20***p*, and the lower SW device **23** is connected to the negative electrode **20***n*. The midpoint of the series-connected circuitry of the upper SW device **22** and the lower SW **10** device is connected to the alternating current terminal. The midpoint of the series-circuit **21***u* (**21***v*, **21***w*) is connected to the alternating current terminal **20***u* (**20***v*, **20***w*).
[0022] Each of the plurality of upper SW devices **22** is associated with a temperature sensor **24**, and each of the plurality of lower SW devices **23** is associated with a temperature sensor **25**.
[0023] The motor **30** includes three stator coils **31***u*, **31***v*, **31***w*. One end of each of the three stator coils **31***u*, **31***v*, **31***w* (the left end of the stator coil in FIG. **1**) is connected to each of the three alternating current terminals **10***u*, **10***v*, **10***w* of the first inverter **10**. The other end of each of the three stator coils **31***u*, **31***v*, **31***w* (the right end of the stator coil in FIG. **1**) is connected to each of the three alternating current terminals **20***u*, **20***v*, **20***w* of the second inverter **20**. Hereinafter, the stator coil **31***u*, **31***v*, **31***w* may be collectively referred to **20** as the stator coil **31**.
[0024] The motor **30** is a three-phase alternating current motor. The suffix "u"/"v"/"w" of the symbol means each phase (u-phase, v-phase, w-phase) of three-phase alternating current. In a normal motor, one end of each of the plurality of stator coils is connected to each of the plurality of alternating current ends of the inverter, and the other ends of the plurality of stator coils are connected to each other. A portion where the other ends of the plurality of stator coils are connected to each other is called a neutral point. In the motor **30**, one end of the plurality of stator coils **31** is connected to the alternating current terminals **10***u*, **10***v*, **10***w* of the first inverter **10**, and the other end is connected to the **30** alternating current terminal **20***u*, **20***v*, **20***w* of the second inverter **20**. The motor **30** having no neutral point is called an open winding type.
[0025] The positive electrode **20***p* and the negative electrode **20***n* of the direct current terminal of the second inverter **20** is connected to the battery **3** via a linking switch **40***p*, **40***n*. Specifically, the positive electrode **20***p* is connected to the positive electrode **3***p* of the battery **3** via the linking switch **40***p*, and the negative electrode **20***n* is connected to the negative electrode **3***n* of the battery **3** via the linking switch **40***n*. When the linking switch **40***p*, **40***n* is closed, the second inverter **20** is connected to the battery **3**, and when at least one of the linking switch **40***p*, **40***n* is opened, the second inverter **20** is disconnected from the battery **3**.

[0026] The controller **50** may drive the motor **30** using both the first inverter **10** and the second inverter **20**. Specifically, the controllers **50** close the linking switch **40***p*, **40***n*. The upper SW device **12***u* and the lower SW device **13***u* of the series-circuit **11***u* are alternately turned on and off. The upper SW device **22***u* of the series **21***u* is turned on and off in a phase opposite to the upper SW device **12***u*, and the lower SW device **23***u* is turned on and off in a phase opposite to the lower SW device **13***u*. The same applies to other series-circuit **11***v*/**21***v* (**11***w*/**21***w*). When SW devices of the first inverter **10** and the second inverter **20** are driven in opposite phases in this manner, a current twice as large flows in the stator coil as compared with when the motor is driven by one inverter. That is, when the motor **30** is driven by the two inverters **10** and **20**, a high torque is obtained. Driving the motor **30** by the first inverter **10** and the second inverter **20** by closing the linking switch **40***p*, **40***n* is hereinafter referred to as a dual mode.
[0027] The controller **50** may open the linking switch **40***p*, **40***n* and drive the motor **30** only by the first inverter **10**. At this time, a neutral point is created in the second inverter **20**. The controller **50** opens the linking switch **40***p* and turns on all the upper SW devices **22***u*, **22***v*, **22***w* of the second inverter **20**. The controllers **50** keep all the lower SW devices **23***u*, **23***v*, **23***w* of the second inverters **20** off. Then, the other ends of the plurality of stator coils **31** (the right end of the stator coil **31** in FIG. **1**) are short-circuited via the upper SW devices **22**. That is, the other ends of the plurality of stator coils **31** are connected to the neutral point. The controllers **50** turn on and off SW devices of the first inverter **10** as appropriate. The motor **30** is driven as a normal motor having a neutral point. The controller **50** using the second inverter **20** to create a neutral point and driving the motor **30** only by the first inverter **10** is hereinafter referred to as a single mode.
[0028] The controller **50** can create a neutral point in two ways: First, as described above, the controllers **50** hold all the upper SW devices **22** of the second inverters **20** on and all the lower SW devices **23** off. The circuit of the second inverter **20** at this time is referred to as an upper short-circuiting circuit. FIG. **2** shows the current flow in the upper short-circuiting circuit. The thick arrow line in FIG. **2** indicates the current flow in the second inverter **20**.
[0029] Another way to create a neutral point is as follows. The controllers **50** hold all the lower SW devices **23** of the second inverters **20** on and all the upper SW devices **22** off. The right ends of the stator coils **31** are short-circuited via the lower SW devices **23**. A circuit in which all the lower SW devices **23** are held on and all the upper SW devices **22** are held off to form a neutral point is referred to as a lower short-circuiting circuit. FIG. **3** shows the current flow in the lower short-circuiting circuit. The thick arrow line in FIG. **3** indicates the current flow in the second inverter **20**.
[0030] The linking switch **40***p*, **40***n* is opened for both the upper short-circuiting circuit and lower short-circuiting circuit. When driving the motor **30** in the single mode, the controller **50** opens the linking switch **40***p*, **40***n* and selects one of the upper short-circuiting circuit and the lower short-circuiting circuit.
[0031] As described above, the first inverter **10** is provided with temperature sensors **14** and **15** for measuring the temperature of SW devices, and the second inverter **20** is provided with temperature sensors **24** and **25** for measuring the temperature of SW devices. The temperature sensor **14** (**24**) measures the temperature of the upper SW device **12** (**22**), and the temperature sensor **15** (**25**) measures the temperature of the lower SW device **13** (**23**). The temperature of SW device is positively correlated with the load of SW device. The controllers **50** compare the loads of the upper SW devices **22** and the lower SW devices **23** before starting the driving of the motor in the single-mode, hold SW devices with low loads on, and hold SW devices with high loads off. More specifically, when the motor **30** is driven in the single-mode, the controllers **50** select the upper short-circuiting circuit when the load of the upper SW devices **22** is smaller than the load of the lower SW devices **23**. Conversely, the controllers **50** select the lower short-circuiting circuit if the load of the upper SW devices **22** is greater than the load of the lower SW devices **23**. As described above, by selecting one of the upper short-circuiting circuit and the lower short-circuiting circuit

based on the load, the load of the upper SW device **22** and the load (cumulative load) of the lower SW device **23** can be leveled.

[0032] The controllers **50** identifies the loads of the upper SW devices **22** and the lower SW devices **23** based on any of the temperatures, the driving times, and the driving times of the upper SW device **22** and the lower SW device **23**. There may be several types of selection methods for upper short-circuiting circuit and lower short-circuiting circuit based on load comparison.

Type 1

[0033] The controllers **50** use the driving times of the upper SW devices **22** and the lower SW devices **23** as indices of loads. That is, when driving the motor in the single mode, the controller **50** selects the lower short-circuiting circuit when the past driving time of the upper SW device **22** of the second inverter **20** in the single mode is longer than the past driving time of the lower SW device **23**. On the other hand, the controllers **50** select the upper short-circuiting circuit when the past driving time of the upper SW devices **22** of the second inverters **20** in the single-mode is shorter than the past driving time of the lower SW devices **23**.

[0034] Alternatively, when the motor **30** is being driven in the single mode, the controller **50** switches from the upper short-circuiting circuit to the lower short-circuiting circuit when the elapsed time of the upper short-circuiting circuit (the driving time of the upper SW device **22**) reaches a predetermined threshold time. When the elapsed time of the lower short-circuiting circuit (the driving time of the lower SW device **23**) reaches a predetermined threshold time, the controller **50** switches from the lower short-circuiting circuit to the upper short circuit. This type employs the latest drive time as an indicator of the load.

Type 2

[0035] The controllers **50** adopt the temperatures of the upper SW devices **22** and the lower SW devices **23** as indices of loads. That is, when the motor is driven in the single-mode, the controller **50** selects the lower short-circuiting circuit when the temperature of the upper SW device **22** of the second inverter **20** is higher than the temperature of the lower SW device **23**. On the other hand, the controllers **50** select the upper short-circuiting circuit when the temperature of the upper SW device **22** is lower than the temperature of the lower SW device **23**.

[0036] Alternatively, when driving the motor in the single-mode, the controller **50** selects the lower short-circuiting circuit when the number of times that the upper SW device **22** has reached the predetermined upper limit temperature in the past is greater than the number of times that the lower SW device **23** has reached the upper limit temperature in the past. On the other hand, when the number of times that the upper SW device **22** has reached the predetermined upper limit temperature in the past is less than the number of times that the lower SW device **23** has reached the upper limit temperature in the past, the controllers **50** select the lower short-circuiting circuit.

[0037] Alternatively, when the motor **30** is being driven using the upper short circuit, the controllers **50** switch from the upper short-circuiting circuit to the lower short-circuiting circuit when the temperature of any of the upper SW devices **22** reaches a predetermined upper limit temperature. When the motor **30** is driven using the lower short circuit, the controller **50** switches from the lower short-circuiting circuit to the upper short-circuiting circuit when the temperature of any of the lower SW devices **23** reaches a predetermined upper limit temperature. In this type, the present SW devices are used as indicators of loads.

Type 3

[0038] The controller **50** adopts the number of times of driving each of the upper short-circuiting circuit and the lower short-circuiting circuit as an index of the load. That is, when the number of times that the number of times of selecting the number of times of the upper short-circuiting circuit is larger than the number of times of selecting the number of times of the upper short-circuiting circuit in the past, the controller **50** selects the lower short- circuiting circuit in the present single mode. In addition, when the number of times that the number of times of selecting the number of times of the upper short-circuiting circuit is smaller than the number of times of selecting the number of times of the upper short-circuiting circuit in the past, the controller **50** selects the upper short-circuiting circuit in the present single mode.

[0039] Points to be noted regarding the technique described in the embodiment will be described. When the motor **30** is driven in the single mode, the controllers **50** open the linking switch **40***p*, **40***n*. The controller **50** opens the linking switch **40***p* when selecting the upper short-circuiting circuit. At this time, since all of the lower SW devices **23** are turned off, the linking switch **40***n* may be either open or closed. Controller **50** opens the linking switch **40***n* when selecting the lower short-circuiting circuit. At this time, since all the upper SW devices **22** are turned off, the linking switching **40***p* may be either open or closed.

[0040] When the direct current terminal and the alternating current terminal of the first inverter **10** are referred to as a first direct current terminal and a first alternating current terminal, and the direct current terminal and the alternating current terminal of the second inverter **20** are referred to as a second direct current terminal and a second alternating current terminal, respectively, the features of DI device **2** of the embodiment can be expressed as follows.

[0041] DI device **2** includes a motor **30** including a plurality of stator coils **31**, a first inverter **10**, a second inverter **20**, a linking switch **40***p*, **40***n*, and a controller **50**. The first inverter **10** includes a first direct current terminal and a plurality of first alternating current terminals, the first direct current terminal is connected to the battery **3**, and each of the plurality of first alternating current terminals is connected to one end of each of the stator coils **31**. The second inverter **20** includes a second direct current end and a plurality of second alternating current ends, the second direct current end is connected to the battery **3**, and each of the plurality of second alternating current ends is connected to the other end of each of the stator coils **31**.

[0042] The linking switch **40***p*, **40***n* connects the second direct current terminal to the battery **3** or disconnects the battery **3**. The controller **50** may execute a dual mode in which the linking switch **40***p*, **40***n* is closed and the motor **30** is driven by the first inverter **10** and the second inverter **20**, and a single mode in which the linking switch **40***p*, **40***n* is opened and the motor **30** is driven only by the first inverter **10**.

[0043] The second inverter **20** includes a plurality of series circuits **21**. Each series circuit **21** includes a series-connected circuit of upper SW devices **22** and lower SW devices **23**. A midpoint of the series connection circuit is connected to the second alternating current terminal.

[0044] When driving the motor **30** in the single mode, the controller turns on all the upper SW devices **22** of the second inverter **20**, and selects one of an upper short-circuiting circuit that turns off all the lower SW devices **23** and a lower short-circuiting circuit that turns on all the lower SW devices **23** of the second inverter **20** and turns off all the upper SW devices **22**. The controllers **50** select the upper short-circuiting circuit when the load of the upper SW devices **22** of the second inverters **20** is smaller than the load of the lower SW devices **23**. The controllers **50** select the lower short-circuiting circuit when the load of the upper SW devices **22** of the second inverters **20** is greater than the load of the lower SW devices **23**.

[0045] The techniques disclosed herein are also applicable to DI having four or more series circuitry and four or more stator coils.

[0046] In the present specification, the expression “turning on the switching device” means connecting the high potential end and the low potential end of the switching device. The expression “turning off the switching device” means that the low potential end of the switching device is electrically disconnected from the high potential end. However, since the diode is connected to the switching device in anti-parallel, even if the switching device is turned off, the reverse flow of the current from the low potential end to the high potential end is allowed.

[0047] The expression “turning on the switching device” is equivalent to the expression “closing the switching device”, and the expression “turning off the switching device” is equivalent to the expression “opening the switching device”.

[0048] Although the specific examples of the present disclosure have been described in detail above, these are merely examples and do not limit the scope of claims. The techniques described in the claims include various modifications and alternations of the specific examples illustrated above. The technical elements described in the present specification or the drawings exhibit technical usefulness alone or in various combinations, and are not limited to the combinations described in the claims at the time of filing. In addition, the techniques illustrated in the present specification or drawings can achieve a plurality of objectives at the same time, and achieving one of the objectives itself has technical usefulness.

Claims

1. A dual inverter system comprising: a motor that includes a plurality of stator coils; a first inverter of which a direct current end is connected to a battery, and each of a plurality of alternating current ends is connected to respective one ends of the stator coils; a second inverter of which a direct current end is connected to the battery and each of a plurality of alternating current ends is connected to respective other ends of the stator coils; a linking switch that is connected between the direct current end of the second inverter and the battery; and a controller that is configured to execute a dual mode in which the linking switch is closed and the motor is driven by the first inverter and the second inverter, and a single mode in which the linking switch is opened and the motor is driven by the first inverter alone, wherein the controller is configured to, when driving the motor in the single mode, select one of an upper short-circuiting circuit in which all upper switching devices of the second inverter are on and all lower switching devices are off, and a lower short-circuiting circuit in which all lower switching devices of the second inverter are on and all upper switching devices are off, select the upper short-circuiting circuit when a load of the upper switching devices of the second inverter is smaller than a load of the lower switching devices, and select the lower short-circuiting circuit when the load of the upper switching devices of the second inverter is greater than the load of the lower switching devices.
2. The dual inverter system according to claim 1, wherein the controller identifies the load based on at least one of a temperature, a driving time, and a count of times of driving, of the upper switching devices and the lower switching devices.