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Fault handling system of solid-state transformer

Abstract

This application provides a fault handling system of a solid-state transformer, including a first power unit and a second power unit that are cascaded and connected. The first power unit includes a first auxiliary supply, a first control module, and a first communication module. The first auxiliary supply and the first control module are both electrically connected to two ends of a first busbar capacitor. The first control module is configured to detect a voltage of the first busbar capacitor. The second power unit includes a second auxiliary supply and a second control module. The second auxiliary supply and the second control module are both electrically connected to two ends of a second busbar capacitor. The first communication module outputs fault information to the second control module when the first control module detects that the voltage of the first busbar capacitor is greater than a threshold.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application is a continuation of U.S. patent application Ser. No. 17/950,792, filed on Sep. 22, 2022, which claims priority to Chinese Patent Application No. 202111106213.9, filed on Sep. 22, 2021. All of the aforementioned patent applications are hereby incorporated by reference in their entireties.

TECHNICAL FIELD

(1) This application relates to the field of electronic technologies, and in particular, to a fault handling system of a solid-state transformer.

BACKGROUND

(2) As a basic device of a power system, a conventional power transformer cannot implement direct-current voltage transform. In recent years, with the rapid development of electronic technologies, a solid-state transformer has attracted wide attention as a new type of transformer. The solid-state transformer has an advantage of a small volume. In addition, the solid-state transformer can further complete tasks such as power quality management and new energy access, and can serve as a key device for voltage transform and energy management in a direct-current power grid. Therefore, the solid-state transformer has become a current research hotspot.

(3) A medium-voltage auxiliary supply of the solid-state transformer may use a distributed structure. The auxiliary supply obtains power by using a busbar of each cascaded unit. If the auxiliary supply is damaged, a busbar capacitor of the cascaded unit damaged during medium-voltage power-on consumes a very small quantity of charges. Consequently, the busbar capacitor is damaged due to an increase of a busbar voltage of the cascaded unit.

SUMMARY

(4) In view of this, this application provides a fault handling system of a solid-state transformer. When any cascaded power unit is faulty, a normally operating power unit can close an auxiliary supply in the normally operating power unit and reduce a voltage of a busbar capacitor in the faulty power unit, to ensure that the voltage of the busbar capacitor in the faulty unit is within a safe range, thereby avoiding further fault spreading and improving reliability of the system.

(5) According to a first aspect, an embodiment of this application provides a fault handling system of a solid-state transformer, including a first power unit and a second power unit that are cascaded and connected. The first power unit includes a first busbar capacitor, a first auxiliary supply, a first control module, and a first communication module. The first communication module is electrically connected to the first control module. The first auxiliary supply and the first control module are both electrically connected to two ends of the first busbar capacitor. The first control module is electrically connected to the first auxiliary supply. The first control module is configured to detect a voltage of the first busbar capacitor. The second power unit includes a second busbar capacitor, a second auxiliary supply, and a second control module. The second control module is electrically connected to the first communication module. The second auxiliary supply and the second control module are both electrically connected to two ends of the second busbar capacitor. The second busbar capacitor is connected in series to the first busbar capacitor. The second control module is electrically connected to the second auxiliary supply. The second control module is configured to

detect a voltage of the second busbar capacitor. The first communication module is configured to output fault information to the second control module when the first control module detects that the voltage of the first busbar capacitor meets a preset condition, for example, the voltage is greater than or equal to a first threshold. The second control module is configured to close the second auxiliary supply when receiving the fault information.

(6) In this embodiment of this application, a first detection circuit in the first power unit detects the voltage of the first busbar capacitor. Therefore, when detecting that the voltage of the first busbar capacitor is greater than or equal to the preset threshold, the first control module in the first power unit may output the fault information to the second control module in the second power unit by using the first communication module. Based on this design, the second control module may close the auxiliary supply in the second power unit based on the received fault information. In this way, not only the voltage of the busbar capacitor in the faulty power unit can be controlled within the safe voltage range, but also the fault can be prevented from being further spread to another normal power unit, thereby improving reliability of the system of the solid-state transformer.

(7) In a possible design, the first control module is configured to close the first auxiliary supply after the first communication module sends the fault information to the second control module. Based on this design, when the power unit is faulty, not only the fault information can be sent to another normally operating power unit, but also the auxiliary supply in the power unit can be closed, to avoid further fault spreading.

(8) In a possible design, the first control module includes a first detection circuit, and the second control module includes a second detection circuit. The first detection circuit is electrically connected to the two ends of the first busbar capacitor to detect the voltage of the first busbar capacitor. The second detection circuit is electrically connected to the two ends of the second busbar capacitor to detect the voltage of the second busbar capacitor. Based on this design, whether the first power unit and the second power unit are faulty may be determined through detection performed by the first detection circuit and the second detection circuit.

(9) In a possible design, the first control module further includes a first control circuit, and the second control module further includes a second control circuit. The first control circuit is electrically connected to the first communication module. The second control circuit is electrically connected to the first communication module. The first control circuit is configured to transmit the fault information to the second control circuit by using the first communication module when the voltage that is of the first busbar capacitor and that is detected by the first detection circuit is greater than or equal to a first threshold. The first control circuit controls a status of the first auxiliary supply based on the voltage of the first busbar capacitor. The second detection circuit transmits the detected voltage of the second busbar capacitor to the second control circuit. The second control circuit is configured to close the second auxiliary supply when receiving the fault information. Based on this design, when the first power unit is faulty, the second power unit may receive the fault information in time, and may close the auxiliary supply in the second power unit in time.

(10) In a possible design, the first control module further includes a first latch circuit. The first latch circuit is electrically connected between the first control circuit and the first auxiliary supply. The first control circuit is configured to output a first signal to the first latch circuit after the first communication module sends the fault information to the second control circuit. The first latch circuit is configured to close the first auxiliary supply based on the first signal. Based on the design of the first latch circuit, the first auxiliary supply may be closed.

(11) In a possible design, the second control module further includes a second latch circuit. The second latch circuit is electrically connected between the second control circuit and the second auxiliary supply. The second control circuit is configured to output a second signal to the second latch circuit after receiving the fault information. The second latch circuit is configured to close the second auxiliary supply based on the second signal. Based on the design of the second latch circuit,

the second auxiliary supply may be closed.

(12) According to a second aspect, an embodiment of this application further provides a fault handling system of a solid-state transformer. The fault handling system of the solid-state transformer includes a first power unit and a second power unit that are cascaded and connected. The first power unit includes a first busbar capacitor and a first auxiliary supply. The first auxiliary supply and the first control module are both electrically connected to two ends of the first busbar capacitor. The first control module is electrically connected to the first auxiliary supply. The first control module includes a first detection circuit. The first detection circuit is electrically connected to the two ends of the first busbar capacitor. The first detection circuit is configured to detect a voltage of the first busbar capacitor. The second power unit includes a second busbar capacitor and a second auxiliary supply. The second auxiliary supply is electrically connected to two ends of the second busbar capacitor. The second busbar capacitor is connected in series to the first busbar capacitor. The first control module is configured to close the first auxiliary supply when the first detection circuit detects that the voltage of the first busbar capacitor is less than or equal to a second threshold.

(13) In this embodiment of this application, the first power unit and the second power unit are cascaded and connected. The first busbar capacitor is connected in series to the second busbar capacitor. A total voltage of the first busbar capacitor and the second busbar capacitor remains unchanged. Therefore, if the first power unit is abnormal, the voltage of the second busbar capacitor decreases when the voltage of the first busbar capacitor increases. Based on this design, the first control module may close the first auxiliary supply when the first detection circuit detects that the voltage of the first busbar capacitor is less than a preset threshold. In this embodiment of this application, each power unit may detect by using a detection circuit of each power unit whether a voltage of a busbar capacitor decreases, and may close an auxiliary supply when it is detected that the voltage of the busbar capacitor decreases to a threshold. Therefore, when any cascaded power unit is faulty, a normally operating power unit can close an auxiliary supply in the normally operating power unit and reduce a voltage of a busbar capacitor in the faulty power unit, to ensure that the voltage of the busbar capacitor in the faulty unit is within a safe range, thereby avoiding further fault spreading.

(14) In a possible design, the second control module includes a second detection circuit. The second detection circuit is electrically connected to the two ends of the second busbar capacitor. The second detection circuit is configured to detect the voltage of the second busbar capacitor. Based on this design, in this embodiment of this application, the first detection circuit may be used to determine whether the first power unit is faulty.

(15) In a possible design, the first control module further includes a first control circuit, and the second control module further includes a second control circuit. The first detection circuit is further configured to transmit the detected voltage of the first busbar capacitor to the first control circuit. The first control circuit is configured to control a status of the first auxiliary supply based on the voltage of the first busbar capacitor. The second detection circuit is further configured to transmit the detected voltage of the second busbar capacitor to the second control circuit. The second control circuit is configured to control a status of the second auxiliary supply based on the voltage of the second busbar capacitor. Based on this design, in this embodiment of this application, the statuses of the first auxiliary supply and the second auxiliary supply may be correspondingly controlled by using the first control circuit and the second control circuit.

(16) In a possible design, the first control module further includes a first latch circuit. The first latch circuit is electrically connected between the first control circuit and the first auxiliary supply. The first control circuit is configured to output a first signal to the first latch circuit when the first detection circuit detects that the voltage of the first busbar capacitor is less than a preset threshold. The first latch circuit is configured to close the first auxiliary supply based on the first signal. Based on the design of the first latch circuit, the first auxiliary supply may be closed.

(17) In a possible design, the second control module further includes a second latch circuit. The second latch circuit is electrically connected between the second control circuit and the second auxiliary supply. The second control circuit is configured to output a second signal to the second latch circuit when the second detection circuit detects that the voltage of the second busbar capacitor is less than or equal to a second threshold. The second latch circuit is configured to close the second auxiliary supply based on the second signal. Based on the design of the second latch circuit, the second auxiliary supply may be closed.

(18) In a possible design, the first power unit further includes a first voltage equalization module, and the second power unit further includes a second voltage equalization module. The first voltage equalization module is connected in series to the second voltage equalization module. The first voltage equalization module is connected in parallel to the two ends of the first busbar capacitor. The second voltage equalization module is connected in parallel to the two ends of the second busbar capacitor. If the voltage of the first busbar capacitor is less than or equal to the second threshold and the first auxiliary supply and the second auxiliary supply are both in a closed state, the first voltage equalization module and the second voltage equalization module equalize the voltages of the first busbar capacitor and the second busbar capacitor. Based on this design, in this embodiment of this application, voltage equalization may be performed on all busbar capacitors by using the first voltage equalization module and the second voltage equalization module, to equalize the voltages of the first busbar capacitor and the second busbar capacitor.

(19) Embodiments of this application provide the fault handling system of the solid-state transformer. When any cascaded power unit is faulty, a normally operating power unit can close an auxiliary supply in the normally operating power unit and reduce a voltage of a busbar capacitor in the faulty power unit, to ensure that the voltage of the busbar capacitor in the faulty unit is within a safe range, thereby avoiding further fault spreading, improving reliability of the system, and reducing a volume and the costs of the product.

Description

BRIEF DESCRIPTION OF DRAWINGS

- (1) FIG. 1 is a schematic diagram of a fault handling system of a solid-state transformer according to an embodiment of this application;
- (2) FIG. 2 is a schematic diagram of a voltage equalization module according to an embodiment of this application;
- (3) FIG. 3 is another schematic diagram of a voltage equalization module according to an embodiment of this application;
- (4) FIG. 4 is another schematic diagram of a voltage equalization module according to an embodiment of this application;
- (5) FIG. 5 is a schematic diagram of a latch circuit according to an embodiment of this application; and
- (6) FIG. 6 is another schematic diagram of a fault handling system of a solid-state transformer according to an embodiment of this application.

DESCRIPTION OF EMBODIMENTS

(7) It should be noted that when an element is described as “connected to” another element, the element may be directly connected to the other element, or an intermediate element may simultaneously exist. When an element is considered as “disposed in” another element, the element may be directly disposed in the other element, or an intermediate element may simultaneously exist.

(8) Unless defined otherwise, all technical and scientific terms used in this specification have the same meaning commonly understood by a person skilled in the art to which this application

belongs. The terms used in the description of this application in this specification are merely for the purpose of describing specific embodiments, and are not intended to limit this application. The term “and/or” used in this specification includes any and all combinations of one or more of the related listed items.

(9) FIG. 1 is a schematic diagram of cascading system architecture of a fault handling system **100** of a solid-state transformer according to an embodiment of this application.

(10) The fault handling system **100** of the solid-state transformer in this embodiment of this application may include a plurality of power units (FIG. 1 is described by using an example of only three power units **10a**, **10b**, and **10c**, and a quantity of power units may be more than three or less than three). The power units **10a**, **10b**, and **10c** may be all configured to convert an alternating-current voltage (for example, an alternating-current medium voltage) into a direct-current low voltage or an alternating-current low voltage. In some scenarios, the medium voltage may be 6 kV-12 kV, and the low voltage may be 100 V-800 V. The plurality of power units are cascaded to form the fault handling system **100** of the solid-state transformer. In an embodiment, the fault handling system **100** of the solid-state transformer may be formed after the power unit **10a**, the power unit **10b**, and the power unit **10c** are cascaded. It may be understood that a cascading connection between the power units **10a**, **10b**, and **10c** may be a series connection between input ends of the power units **10a**, **10b**, and **10c**, and a parallel connection between output ends of the power units **10a**, **10b**, and **10c**.

(11) It may be understood that, in this embodiment of this application, a first alternating-current input end after the plurality of power units **10a**, **10b**, and **10c** are cascaded may be connected to a first end of a medium-voltage alternating-current power grid, and a second alternating-current input end after the plurality of power units **10a**, **10b**, and **10c** are cascaded may be connected to a second end of the medium-voltage alternating-current power grid. After direct-current output sides of the power units **10a**, **10b**, and **10c** are connected in parallel to form a direct-current output port, the direct-current output port is connected to a low-voltage direct-current power grid or a load.

(12) For example, the power unit **10a** may include an AC-DC converter **11a**, a voltage equalization module **12a**, a busbar capacitor **13a**, an auxiliary supply **14a**, a DC-DC converter **17a**, and a control module **20a**. It may be understood that the control module **20a** may include a latch circuit **15a**, a control circuit **16a**, and a detection circuit **19a**. The auxiliary supply **14a** may be configured to supply power to the control module **20a** in the power unit **10a**. For example, the auxiliary supply **14a** may supply power to the latch circuit **15a**, the control circuit **16a**, and the detection circuit **19a**. An input-end positive electrode of the AC-DC converter **11a** is electrically connected to the first end of the medium-voltage alternating-current power grid. An input-end negative electrode of the AC-DC converter **11a** is electrically connected to an input-end positive electrode of the power unit **10b**. Two ends of the busbar capacitor **13a** are respectively electrically connected to two output ends of the AC-DC converter **11a**. The busbar capacitor **13a** is connected in parallel to the voltage equalization module **12a**. The auxiliary supply **14a** is electrically connected to the two ends of the busbar capacitor **13a**. The latch circuit **15a** is electrically connected to the auxiliary supply **14a** and the control circuit **16a**. The control circuit **16a** is electrically connected to the auxiliary supply **14a**. Two input ends of the DC-DC converter **17a** are respectively electrically connected to two input ends of the AC-DC converter **11a**. Two ends of the detection circuit **19a** are respectively electrically connected to the two ends of the busbar capacitor **13a**. It may be understood that, in a possible implementation, the auxiliary supply **14a** may be a medium-voltage auxiliary supply.

(13) It may be understood that the power unit **10b** may include an AC-DC converter **11b**, a voltage equalization module **12b**, a busbar capacitor **13b**, an auxiliary supply **14b**, a DC-DC converter **17b**, and a control module **20b**. The control module **20b** may include a latch circuit **15b**, a control circuit **16b**, and a detection circuit **19b**. The auxiliary supply **14b** may be configured to supply power to the control module **20b** in the power unit **10b**. For example, the auxiliary supply **14b** may supply power to the latch circuit **15b**, the control circuit **16b**, and the detection circuit **19b**. An alternating-

current input end of the AC-DC converter **11b** is electrically connected to the input-end negative electrode of the AC-DC converter **11a**. An input-end negative electrode of the AC-DC converter **11b** is electrically connected to an input-end positive electrode of the power unit **10c**. Two ends of the busbar capacitor **13b** are respectively electrically connected to two output ends of the AC-DC converter **11b**. The busbar capacitor **13b** is connected in parallel to the voltage equalization module **12b**. The auxiliary supply **14b** is electrically connected to the two ends of the busbar capacitor **13b**. The latch circuit **15b** is electrically connected to the auxiliary supply **14b** and the control circuit **16b**. The control circuit **16b** is electrically connected to the auxiliary supply **14b**. Two input ends of the DC-DC converter **17b** are respectively electrically connected to two input ends of the AC-DC converter **11b**. Two ends of the detection circuit **19b** are respectively electrically connected to the two ends of the busbar capacitor **13b**. It may be understood that, in a possible implementation, the auxiliary supply **14b** may be a medium-voltage auxiliary supply.

(14) The power unit **10c** may include an AC-DC converter **11c**, a voltage equalization module **12c**, a busbar capacitor **13c**, an auxiliary supply **14c**, a DC-DC converter **17c**, and a control module **20c**. The control module **20c** may include a latch circuit **15c**, a control circuit **16c**, and a detection circuit **19c**. The auxiliary supply **14c** may be configured to supply power to the control module **20c** in the power unit **10c**. For example, the auxiliary supply **14c** may supply power to the latch circuit **15c**, the control circuit **16c**, and the detection circuit **19c**. An input-end positive electrode of the AC-DC converter **11c** is electrically connected to the input-end negative electrode of the AC-DC converter **11b**. An input-end negative electrode of the AC-DC converter **11c** is electrically connected to the second end of the medium-voltage alternating-current power grid. Two ends of the busbar capacitor **13c** are respectively electrically connected to two output ends of the AC-DC converter **11c**. The busbar capacitor **13c** is connected in parallel to the voltage equalization module **12c**. The auxiliary supply **14c** is electrically connected to the two ends of the busbar capacitor **13c**. The latch circuit **15c** is electrically connected to the auxiliary supply **14c** and the control circuit **16c**. The control circuit **16c** is electrically connected to the auxiliary supply **14c**. Two input ends of the DC-DC converter **17c** are respectively electrically connected to two input ends of the AC-DC converter **11c**. It may be understood that, in a possible implementation, the auxiliary supply **14c** may be a medium-voltage auxiliary supply.

(15) It may be understood that, because the power unit **10a**, the power unit **10b**, and the power unit **10c** are cascaded and connected, that is, input ends of the power units **10a**, **10b**, and **10c** are connected in series, output ends of the power units **10a**, **10b**, and **10c** are connected in parallel. Based on this design, the busbar capacitor **13a**, the busbar capacitor **13b**, and the busbar capacitor **13c** are connected in series.

(16) In this embodiment, a direct-current output port is formed after a direct-current output side of the DC-DC converter **17a**, a direct-current output side of the DC-DC converter **17b**, and a direct-current output side of the DC-DC converter **17c** are connected in parallel or in series. The direct-current output port is connected to the low-voltage direct-current power grid, an inverter, or a load.

(17) If any auxiliary supply or an MCU in the fault handling system **100** of the solid-state transformer is faulty, a latch circuit in another normally operating power unit may close a corresponding auxiliary supply. Specifically, the normally operating latch circuit may close the auxiliary supply obtaining power from a busbar. Unless the busbar is powered on again after power failure, the auxiliary supply cannot be enabled again.

(18) For example, the auxiliary supply **14a** in the power unit **10a** is faulty and the auxiliary supply **14b** and the auxiliary supply **14c** are both normal, and an output end of the auxiliary supply **14a** cannot output a voltage to the control circuit **16a**. In this case, the control circuit **16a** is in a non-operating state, and a voltage of the busbar capacitor **13a** increases. The busbar capacitor **13a** is connected in series to the busbar capacitor **13b**. A total voltage of all busbar capacitors connected in series remains unchanged. Therefore, when a voltage of the busbar capacitor **13a** increases, the detection circuit **19b** may detect a voltage drop of the busbar capacitor **13b**, and transmit a detected

voltage signal to the control circuit **16b**. When a voltage of the busbar capacitor **13b** is less than or equal to a second threshold, the control circuit **16b** may determine that one of cascaded power units is faulty. The control circuit **16b** outputs a control signal to the latch circuit **15b**, and the latch circuit **15b** closes the auxiliary supply **14b**. It may be understood that the detection circuit **19c** detects a voltage drop of the busbar capacitor **13c**, and transmits a detected voltage signal to the control circuit **16c**. When a voltage of the busbar capacitor **13c** is less than or equal to the second threshold, the control circuit **16c** may determine that one of the cascaded power units is faulty. The control circuit **16c** outputs a control signal to the latch circuit **15c**. The latch circuit **15c** may close the auxiliary supply **14c**. Because the auxiliary supply **14b** and the auxiliary supply **14c** are both in a closed state, that is, the auxiliary supply **14b** and the auxiliary supply **14c** do not operate, the voltage of the busbar capacitor **13b** and the voltage of the busbar capacitor **13c** both increase, to reduce the voltage of the busbar capacitor **13a** and avoid an electrolyte overflow caused due to the excessively high voltage of the busbar capacitor **13a**. In addition, the voltage equalization module **12b** and the voltage equalization module **12c** may respectively perform voltage equalization on the voltage of the busbar capacitor **13b** and the voltage of the busbar capacitor **13c**, to equalize the voltage of the busbar capacitor **13b** and the voltage of the busbar capacitor **13c**.

(19) The auxiliary supply **14a** in the power unit **10a** is faulty and the auxiliary supply **14b** and the auxiliary supply **14c** are both normal, and the output end of the auxiliary supply **14a** can output a voltage to the control circuit **16a**. In this case, the voltage of the busbar capacitor **13a** increases. The control circuit **16a** is in an operating state, and outputs a control signal to the latch circuit **15a**, to control the latch circuit **15a** to close the auxiliary supply **14a**. In this case, the detection circuit **19b** and the detection circuit **19c** respectively detect a voltage change of the busbar capacitor **13b** and a voltage change of the busbar capacitor **13c**. The control circuit **16b** and the control circuit **16c** respectively output control signals to the latch circuit **15b** and the latch circuit **15c**. The latch circuit **15b** and the latch circuit **15c** may respectively close the auxiliary supply **14b** and the auxiliary supply **14c**. The auxiliary supply **14a**, the auxiliary supply **14b**, and the auxiliary supply **14c** are all in the closed state. Therefore, in this case, the voltages of the busbar capacitors in all the power units connected in series are imposed only on the voltage equalization modules. The voltage equalization modules re-allocate and equalize the voltages of the busbar capacitors in all the power units connected in series, to reduce the voltage of the busbar capacitor in the faulty power unit.

(20) Based on this design, it can be ensured that the voltage of the busbar capacitor in the faulty power unit is within a safe range. For example, that the busbar capacitor **13a** is connected in parallel to the voltage equalization module **12a** may be that voltage equalization is automatically performed by using a passive component on the voltages of the busbar capacitors connected in series. When a voltage of one of the capacitors connected in series increases, a current consumed on a resistor connected in parallel to the capacitor increases, to reduce the voltage of the capacitor. In this way, the voltages of the capacitors connected in series are in a voltage-equalized state, to avoid out-of-control due to over-voltage caused by the positive feedback.

(21) In this embodiment, a non-faulty power unit may detect a voltage waveform of a busbar capacitor in the non-faulty power unit. The voltage waveform is inconsistent with a normal voltage equalization waveform. Therefore, when the voltage waveform keeps falling, the control module may send a control indication to the latch circuit, to close the auxiliary supply.

(22) FIG. 2 is a diagram of a circuit structure of a voltage equalization module according to an embodiment of this application.

(23) It may be understood that a structure of the voltage equalization module **12a** is fully the same as those of the voltage equalization module **12b** and the voltage equalization module **12c**. In this embodiment, the voltage equalization module **12a** is used as an example. The voltage equalization module **12a** may include a capacitor C1, a capacitor C2, a resistor R1, and a resistor R2.

(24) In this embodiment, a first end of the capacitor C1 is electrically connected to the first end of the busbar capacitor **13a**, a second end of the capacitor C1 is electrically connected to a first end of

the capacitor C2, and a second end of the capacitor C2 is electrically connected to the second end of the busbar capacitor 13a. A first end of the resistor R1 is electrically connected to the first end of the capacitor C1, a second end of the resistor R1 is electrically connected to the second end of the capacitor C1, a first end of the resistor R2 is electrically connected to a first end of the capacitor C2, and a second end of the resistor R2 is electrically connected to a second end of the capacitor C2.

(25) FIG. 3 is a diagram of a circuit structure of a voltage equalization module according to another embodiment of this application.

(26) A difference between the voltage equalization module in this embodiment and the voltage equalization module shown in FIG. 2 is that, as shown in FIG. 3, in this embodiment, the voltage equalization module (for example, the voltage equalization module 12a) may further include a Zener diode D1 and a Zener diode D2.

(27) In this embodiment, a first end of the capacitor C1 is electrically connected to the first end of the busbar capacitor 13a, a second end of the capacitor C1 is electrically connected to a first end of the capacitor C2, and a second end of the capacitor C2 is electrically connected to the second end of the busbar capacitor 13a. A first end of the resistor R1 is electrically connected to the first end of the capacitor C1, a second end of the resistor R1 is electrically connected to a cathode of the Zener diode D1, and an anode of the Zener diode D2 is electrically connected to the second end of the capacitor C1. A first end of the resistor R2 is electrically connected to the first end of the capacitor C2, a second end of the resistor R2 is electrically connected to a cathode of the Zener diode D2, and an anode of the Zener diode D2 is electrically connected to the second end of the capacitor C2.

(28) FIG. 4 is a diagram of a circuit structure of a voltage equalization module according to another embodiment of this application.

(29) A difference between the voltage equalization module in this embodiment and the voltage equalization module shown in FIG. 2 is that, as shown in FIG. 4, in this embodiment, the voltage equalization module (for example, the voltage equalization module 12a) may further include a Zener diode D1, a Zener diode D2, a resistor R3, and a resistor R4.

(30) In this embodiment, a first end of the capacitor C1 is electrically connected to the first end of the busbar capacitor 13a, a second end of the capacitor C1 is electrically connected to a first end of the capacitor C2, and a second end of the capacitor C2 is electrically connected to the second end of the busbar capacitor 13a.

(31) A first end of the resistor R1 is electrically connected to the first end of the capacitor C1, a second end of the resistor R1 is electrically connected to a first end of the resistor R3, a second end of the resistor R3 is electrically connected to the second end of the capacitor C1, a cathode of the Zener diode D1 is electrically connected to a node between the second end of the resistor R1 and the first end of the resistor R3, and an anode of the Zener diode D1 is electrically connected to the second end of the capacitor C1. A first end of the resistor R2 is electrically connected to the first end of the capacitor C2, a second end of the resistor R2 is electrically connected to a first end of the resistor R4, a second end of the resistor R4 is electrically connected to the second end of the capacitor C2, a cathode of the Zener diode D2 is electrically connected to a node between the second end of the resistor R2 and the first end of the resistor R4, and an anode of the Zener diode D2 is electrically connected to the second end of the capacitor C2.

(32) FIG. 5 is a diagram of a circuit structure of a latch circuit according to an embodiment of this application.

(33) It may be understood that a structure of the latch circuit 15a is fully the same as those of the latch circuit 15b and the latch circuit 15c. In this embodiment, the latch circuit 15a is used as an example for description. The latch circuit 15a may include an opto-isolator U1, a processing chip U2, transistors Q1-Q2, diodes D3-D4, capacitors C3-C4, an inductor L1, and resistors R5-R11.

(34) The opto-isolator U1 may include a light-emitting unit and a switch unit. The switch unit includes an emitter and a collector. A cathode of the light-emitting unit is electrically connected to a

node between a control pin IO of the control circuit **16a** and a first end of the resistor R5, an anode of the light-emitting unit is electrically connected to a node between a second end of the resistor R5 and a first end of the resistor R6, and a second end of the resistor R6 is electrically connected to a first power supply +15 V. An emitter of the switch unit is grounded by using the resistor R7, and a collector of the switch unit is electrically connected to a first signal pin of the processing chip U2 by using the resistor R8.

(35) A base of the transistor Q1 is electrically connected to a collector of the transistor Q2 and an emitter of the switch unit, an emitter of the transistor Q1 is grounded, and a collector of the transistor Q1 is electrically connected to the first signal pin of the processing chip U2 sequentially through the resistor R9 and the resistor R10. A base of the transistor Q2 is electrically connected to a node between the collector of the transistor Q1 and the resistor R9, a collector of the transistor Q2 is grounded by using a capacitor C3, an emitter of the transistor Q2 is electrically connected to a node between the resistor R9 and the resistor R10, a cathode of the diode D3 is electrically connected to a node between the collector of the transistor Q1 and the resistor R9, and an anode of the diode D3 is electrically connected to a second signal pin of the processing chip U2. A first end of the resistor R11 is electrically connected to the first signal pin of the processing chip U2, the first end of the resistor R11 is further grounded by using the capacitor C4, a second end of the resistor R11 is electrically connected to a cathode of the diode D4, and an anode of the diode D4 is grounded by using the inductor L1.

(36) It may be understood that the control pin IO of the control circuit **16a** sends a signal to the opto-isolator U1. When a signal output by the control pin IO is a low-level signal, the opto-isolator U1 is on to control the transistor Q1 to be on. After the transistor Q1 is on, the base of the transistor Q2 is pulled down to a low level state, and the second signal pin of the processing chip U2 is also pulled down to the low level state. In this case, the processing chip U2 does not send a control signal, and the auxiliary supply **14a** has no output. In addition, the transistor Q1 is on, and the transistor Q1 and the transistor Q2 may form an interlock circuit. When a busbar voltage exists, the transistor Q1 and the transistor Q2 are constantly in an on state, and the processing chip U2 cannot reach a power-on voltage of the processing chip U2. Therefore, only when the busbar voltage disappears and fully discharges, the transistor Q1 and the transistor Q2 are no longer on, and the processing chip U2 can reach the power-on voltage of the processing chip U2 and start to operate normally.

(37) In this embodiment, the control module may detect a voltage waveform of the busbar capacitor by using the detection circuit. For example, the control circuit **16a** may detect the voltage waveform of the busbar capacitor **13a** by using the detection circuit **19a**, determine whether the voltage waveform is normal, and send a corresponding control signal to the latch circuit **15a**. It may be understood that, in some possible embodiments, the control module may be formed by a micro control unit (MCU) and a peripheral circuit of the micro control unit, or may be formed by a peripheral circuit of another data processing control chip such as digital signal processing (DSP) or an advanced RISC machine (ARM).

(38) FIG. 6 is a schematic diagram of another embodiment of a fault handling system **100** of a solid-state transformer according to this application.

(39) A difference between the fault handling system **100** of the solid-state transformer in this embodiment and the fault handling system **100** of the solid-state transformer shown in FIG. 1 is that, as shown in FIG. 6, each power unit in this embodiment may further include a communication module, and the communication module establishes a communication connection to the control module.

(40) For example, the power unit **10a** may further include a communication module **18a**, the power unit **10b** may further include a communication module **18b**, and the power unit **10c** may further include a communication module **18c**. The communication module **18a** is connected to the control circuit **16a** and the communication module **18b** in a communication manner, the communication

module **18b** is connected to the control circuit **16b** and the communication module **18c** in a communication manner, and the communication module **18c** is connected to the control circuit **16c** in a communication manner. For example, an operation parameter of the power unit **10a** may be transmitted to the control circuit in the power unit **10b** by using the communication module **18a**. An operation parameter of the power unit **10b** may be transmitted to the control circuit in the power unit **10a** by using the communication module **18a**. It may be understood that an auxiliary supply in each power unit may be configured to supply power to a corresponding communication module. For example, the auxiliary supply **14a** may be configured to supply power to the communication module **18a**, the auxiliary supply **14b** may be configured to supply power to the communication module **18b**, and the auxiliary supply **14c** may be configured to supply power to the communication module **18c**.

(41) Based on this design, signals are transmitted between the power unit **10a**, the power unit **10b**, and the power unit **10c** by using the communication module **18a**, the communication module **18b**, and the communication module **18c**. When the power units in the fault handling system **100** of the solid-state transformer operate normally, all the power units may communicate with each other to transmit information indicating that a busbar voltage is normal.

(42) When a power unit is faulty, another normally operating power unit may receive fault information. The faulty power unit closes an auxiliary supply in the faulty power unit, and transmits the fault information to an adjacent power unit, to close auxiliary supplies of all normally operating power units.

(43) For example, when the power unit **10a**, the power unit **10b**, and the power unit **10c** operate normally, communication is performed between the power unit **10a**, the power unit **10b**, and the power unit **10c**, to mutually transmit information indicating that the voltage of the busbar capacitor is normal. When one of the power unit **10a**, the power unit **10b**, and the power unit **10c** is faulty, for example, when the power unit **10a** is faulty, that is, the power unit **10a** detects by using the detection circuit **19a** that the voltage of the busbar capacitor **13a** is greater than or equal to a first threshold, the communication module **18a** in the power unit **10a** may send the fault information to the control module **20b** in the power unit **10b**. For example, the communication module **18a** may send the fault information to the control circuit **16b**, and then the control circuit **16a** in the power unit **10a** outputs a control signal to the latch circuit **15a**, so that the latch circuit **15a** can close the auxiliary supply **14a**. When the control circuit **16b** in the power unit **10b** receives the fault information, the control circuit **16b** may further output a control signal to the latch circuit **15b** after the fault information of the power unit **10a** is transmitted to the control circuit **16c** in the power unit **10c**, and the latch circuit **15b** may close the auxiliary supply **14b**. After receiving the fault information of the power unit **10a**, the control circuit **16c** in the power unit **10c** may transmit the fault information of the power unit **10a** to a next-level power unit. The control circuit **16c** further outputs a control signal to the latch circuit **15c**, and the latch circuit **15c** may close the auxiliary supply **14c**.

(44) Embodiments of this application provide the fault handling system **100** of the solid-state transformer. When any cascaded power unit is faulty, a normally operating power unit can close an auxiliary supply in the normally operating power unit and reduce a voltage of a busbar capacitor in the faulty power unit, to ensure that the voltage of the busbar capacitor in the faulty unit is within a safe range, thereby avoiding further fault spreading, improving reliability of the system, and reducing a volume and the costs of the product. A person of ordinary skill in the art should understand that the foregoing implementations are merely intended to describe this application but are not intended to limit this application, provided that proper modifications and changes made to the foregoing embodiments in the essential scope of this application fall within the protection scope of this application.

Claims

1. A fault handling system of a solid-state transformer, comprising a first power unit and a second power unit that are cascaded and connected, wherein the first power unit comprises a first busbar capacitor, a first auxiliary supply, and a first control module, wherein the first auxiliary supply is configured to supply power to the first control module, the first auxiliary supply is electrically connected to two ends of the first busbar capacitor, and the first control module is configured to detect a voltage of the first busbar capacitor; the second power unit comprises a second busbar capacitor, a second auxiliary supply, and a second control module, wherein the second auxiliary supply is configured to supply power to the second control module, the second auxiliary supply is electrically connected to two ends of the second busbar capacitor, the second busbar capacitor is connected in series to the first busbar capacitor, and the second control module is configured to detect a voltage of the second busbar capacitor; and in response to detecting that the voltage of the first busbar capacitor is greater than or equal to a first threshold, the second control module is configured to close the second auxiliary supply.
2. The fault handling system of a solid-state transformer according to claim 1, wherein: the first control module comprises a first detection circuit, the second control module comprises a second detection circuit, the first detection circuit is electrically connected to the two ends of the first busbar capacitor to detect the voltage of the first busbar capacitor, and the second detection circuit is electrically connected to the two ends of the second busbar capacitor to detect the voltage of the second busbar capacitor.
3. The fault handling system of a solid-state transformer according to claim 1, wherein the first power unit comprises a first communication module, the first communication module is configured to output fault information to the second control module in response to detecting that the voltage of the first busbar capacitor is greater than or equal to the first threshold.
4. The fault handling system of a solid-state transformer according to claim 3, wherein: the first control module is configured to close the first auxiliary supply after the first communication module sends the fault information to the second control module.
5. The fault handling system of a solid-state transformer according to claim 2, wherein: the first control module further comprises a first control circuit, and the second control module further comprises a second control circuit; the first control circuit is configured to transmit the fault information to the second control circuit in response to detecting that the voltage of the first busbar capacitor and that is detected by the first detection circuit is greater than or equal to the first threshold, and the first control circuit controls a status of the first auxiliary supply based on the voltage of the first busbar capacitor; and the second detection circuit transmits the detected voltage of the second busbar capacitor to the second control circuit, and the second control circuit is configured to close the second auxiliary supply in response to receiving the fault information.
6. The fault handling system of a solid-state transformer according to claim 3, wherein: the first control module further comprises a first control circuit, the second control module further comprises a second control circuit, the first control circuit is electrically connected to the first communication module, and the second control circuit is electrically connected to the first communication module; the first control circuit is configured to transmit the fault information to the second control circuit by using the first communication module in response to detecting that the voltage of the first busbar capacitor and that is detected by the first detection circuit is greater than or equal to the first threshold, and the first control circuit controls a status of the first auxiliary supply based on the voltage of the first busbar capacitor; and the second detection circuit transmits the detected voltage of the second busbar capacitor to the second control circuit, and the second control circuit is configured to close the second auxiliary supply in response to receiving the fault information.

7. The fault handling system of a solid-state transformer according to claim 1, wherein: the first control module further comprises a first latch circuit and a first control circuit, the first latch circuit is electrically connected between the first control circuit and the first auxiliary supply, the first control circuit is configured to output a first signal to the first latch circuit after the first control module sends fault information to the second control circuit, and the first latch circuit is configured to close the first auxiliary supply based on the first signal.

8. The fault handling system of a solid-state transformer according to claim 1, wherein: the second control module further comprises a second latch circuit and a second control circuit, the second latch circuit is electrically connected between the second control circuit and the second auxiliary supply, the second control circuit is configured to output a second signal to the second latch circuit after receiving fault information, and the second latch circuit is configured to close the second auxiliary supply based on the second signal.

9. A fault handling system of a solid-state transformer, comprising a first power unit and a second power unit that are cascaded and connected, wherein: the first power unit comprises a first busbar capacitor and a first auxiliary supply, wherein the first auxiliary supply is configured to supply power to a first control module, the first auxiliary supply is electrically connected to two ends of the first busbar capacitor, and the first control module is configured to detect a voltage of the first busbar capacitor; the second power unit comprises a second busbar capacitor and a second auxiliary supply, wherein the second auxiliary supply is configured to supply power to a second control module, the second auxiliary supply is electrically connected to two ends of the second busbar capacitor, and the second busbar capacitor is connected in series to the first busbar capacitor; and the first control module is configured to close the first auxiliary supply in response to detecting that the voltage of the first busbar capacitor is less than or equal to a second threshold.

10. The fault handling system of a solid-state transformer according to claim 9, wherein: the first control module comprises a first detection circuit, the first detection circuit is electrically connected to the two ends of the first busbar capacitor to detect the voltage of the first busbar capacitor; and the second control module comprises a second detection circuit, the second detection circuit is electrically connected to the two ends of the second busbar capacitor, and the second detection circuit is configured to detect a voltage of the second busbar capacitor.

11. The fault handling system of a solid-state transformer according to claim 10, wherein: the first control module further comprises a first control circuit, and the second control module further comprises a second control circuit; the first detection circuit is further configured to transmit the detected voltage of the first busbar capacitor to the first control circuit, and the first control circuit is configured to control a status of the first auxiliary supply based on the voltage of the first busbar capacitor; and the second detection circuit is further configured to transmit the detected voltage of the second busbar capacitor to the second control circuit, and the second control circuit is configured to control a status of the second auxiliary supply based on the voltage of the second busbar capacitor.

12. The fault handling system of a solid-state transformer according to claim 10, wherein: the first control module further comprises a first latch circuit, the first latch circuit is electrically connected between a first control circuit and the first auxiliary supply, the first control circuit is configured to output a first signal to the first latch circuit in response to the first detection circuit detecting that the voltage of the first busbar capacitor is less than or equal to the second threshold, and the first latch circuit is configured to close the first auxiliary supply based on the first signal.

13. The fault handling system of a solid-state transformer according to claim 11, wherein the first control module further comprises a first latch circuit, the first latch circuit is electrically connected between the first control circuit and the first auxiliary supply, the first control circuit is configured to output a first signal to the first latch circuit in response to the first detection circuit detecting that the voltage of the first busbar capacitor is less than or equal to the second threshold, and the first latch circuit is configured to close the first auxiliary supply based on the first signal.

14. The fault handling system of a solid-state transformer according to claim 10, wherein: the second control module further comprises a second latch circuit, the second latch circuit is electrically connected between a second control circuit and the second auxiliary supply, the second control circuit is configured to output a second signal to the second latch circuit in response to the second detection circuit detecting that the voltage of the second busbar capacitor is less than or equal to the second threshold, and the second latch circuit is configured to close the second auxiliary supply based on the second signal.

15. The fault handling system of a solid-state transformer according to claim 11, wherein: the second control module further comprises a second latch circuit, the second latch circuit is electrically connected between the second control circuit and the second auxiliary supply, the second control circuit is configured to output a second signal to the second latch circuit in response to the second detection circuit detecting that the voltage of the second busbar capacitor is less than or equal to the second threshold, and the second latch circuit is configured to close the second auxiliary supply based on the second signal.

16. The fault handling system of a solid-state transformer according to claim 12, wherein: the second control module further comprises a second latch circuit, the second latch circuit is electrically connected between the second control circuit and the second auxiliary supply, the second control circuit is configured to output a second signal to the second latch circuit in response to the second detection circuit detecting that the voltage of the second busbar capacitor is less than or equal to the second threshold, and the second latch circuit is configured to close the second auxiliary supply based on the second signal.

17. The fault handling system of a solid-state transformer according to claim 9, wherein: the first power unit further comprises a first voltage equalization module, the second power unit further comprises a second voltage equalization module, the first voltage equalization module is connected in series to the second voltage equalization module, the first voltage equalization module is connected in parallel to the two ends of the first busbar capacitor, and the second voltage equalization module is connected in parallel to the two ends of the second busbar capacitor; and in response to detecting that the voltage of the first busbar capacitor is less than or equal to a preset threshold and the first auxiliary supply and the second auxiliary supply are both in a closed state, the first voltage equalization module and the second voltage equalization module equalize the voltages of the first busbar capacitor and the second busbar capacitor.
