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(71) Applicants:
- **KABUSHIKI KAISHA TOSHIBA**
Minato-ku
Tokyo
105-0023 (JP)
- **Toshiba Energy Systems & Solutions Corporation**
Saiwai-ku
Kawasaki-shi
Kanagawa 2120013 (JP)

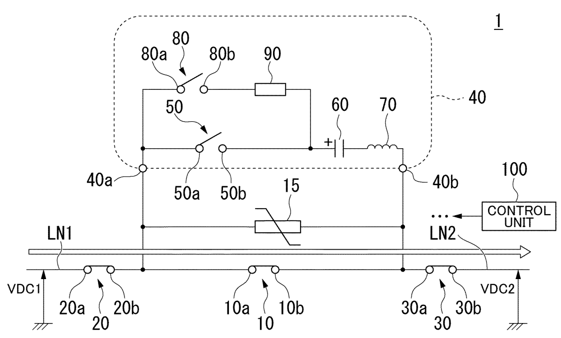
(72) Inventors:
- **HASHIMOTO, Yuhei**
Kawasaki-shi, Kanagawa 212-0013 (JP)
- **MIYAZAKI, Kensaku**
Kawasaki-shi, Kanagawa 212-0013 (JP)

(74) Representative: **Henkel & Partner mbB**
Patentanwaltskanzlei, Rechtsanwaltskanzlei
Maximiliansplatz 21
80333 München (DE)

(54) DIRECT-CURRENT CIRCUIT BREAKER

(57) This direct-current circuit breaker has a mechanical circuit breaker, a surge arrester, and a commutation circuit. The mechanical circuit breaker is connected to a first direct-current transmission line at a first end thereof and to a second direct-current transmission line at a second end thereof. The commutation circuit has a first switch, a second switch, a reactor, a capacitor, and a resistor. The commutation circuit, the surge arrester, and the mechanical circuit breaker are parallelly connected between the first direct-current transmission line and the second direct-current transmission line. The first switch, the capacitor, and the reactor are serially connected between the first direct-current transmission line and the second direct-current transmission line. The second switch and the resistor are serially connected and disposed in parallel with the first switch.

FIG. 1



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Description

[Technical Field]

[0001] The present invention relates to a DC circuit breaker.

[Background Art]

[0002] In recent years, power has been transmitted by a DC transmission network in which a plurality of DC transmission lines are configured in a grid shape. In the DC transmission network, when an accident occurs, only a specific transmission line may be cut off and the remaining transmission lines may continue to transmit power. In this regard, technologies for DC cutoff devices that cut off a current flowing through a DC transmission line are known.

[0003] Incidentally, a DC circuit breaker has a semiconductor cutoff method using a semiconductor circuit breaker, a mechanical cutoff method using a mechanical circuit breaker, and a hybrid cutoff method using both a semiconductor circuit breaker and a mechanical circuit breaker. A DC circuit breaker for the mechanical cutoff method closes a commutation circuit including a commutation switch, a commutation capacitor, and a commutation reactor, and creates a zero point by generating a resonant current in a current flowing through the DC transmission line, thereby cutting off the mechanical circuit breaker and cutting off the current flowing through the DC transmission line.

[0004] In addition, the commutation switch may have a mechanical method in which one or both of the electrodes are mechanically moved to create a conduction state between the electrodes electrically and mechanically, a semiconductor method in which semiconductor elements such as thyristors and insulated gate bipolar transistors (IGBT) are used to create the conduction state, and a discharge method in which insulation performance is lowered by adding an external factor between the fixed electrodes to create the conduction state electrically. Furthermore, the commutation switch of the mechanical method may have a contact method in which a pair of electrodes are provided, at least one of the electrodes is moved to make a distance between the electrodes shorter, and dielectric breakdown is caused by lowering the insulation performance between the electrodes to below that in an open state to create a closed state, a non-contact method in which a pair of fixed electrodes are provided, dielectric breakdown is caused by lowering the insulation performance between the electrodes to below that in an open state to create a closed state.

[0005] Here, the commutation switch of the mechanical method is brought into an electrical conduction state by generating an arc due to the dielectric breakdown between electrodes in the closed state. Therefore, the commutation switch of the mechanical method has a problem that peripheral circuit elements and other peripheral devices may malfunction or fail due to the occurrence of a surge due to dielectric breakdown.

[0006] In addition, the DC circuit breaker may be required to be responsible for reclosing. In the DC circuit breakers of the hybrid cutoff method and the semiconductor cutoff method, since the commutation capacitor is charged by a recovery voltage when an accident current is cut off, it is possible to cause a mechanical circuit breaker to be cut off and to cut off the current flowing through the DC transmission line even after the reclosing is performed.

[0007] On the other hand, in the DC circuit breaker using the commutation switch of the mechanical method, since a current flowing between the electrodes is cut off by recovering the insulation performance between the electrodes of the commutation switch or an arc is extinguished at the zero point of the current, the DC circuit breaker may terminate the electrical conduction state with a charging state of the commutation capacitor being inappropriate. In this case, there is a problem that the commutation capacitor may not be sufficiently charged or be overcharged by a predetermined voltage and may not be able to perform reclosing properly.

[Citation List]

[Patent Literature]

[Patent Literature 1]

[0008] PCT International Publication No. WO 2015/166600

[Summary of Invention]

[Technical Problem]

[0009] An object of the present invention is to provide a DC circuit breaker capable of appropriately performing reclosing while a surge is suppressed.

[Solution to Problem]

[0010] The DC circuit breaker of an embodiment has a mechanical circuit breaker, a lightning arrester, and a commutation circuit. The mechanical circuit breaker has a first end connected to a first DC transmission line and a second end connected to a second DC transmission line. The commutation circuit has a first switch, a second switch, a reactor, a capacitor, and a resistor. The commutation circuit, the lightning arrester, and the mechanical circuit breaker are connected in parallel between the first DC transmission line and the second DC transmission line. The first switch, the capacitor, and the reactor are connected in series between the first DC transmission line and the second DC transmission line. The second switch and the resistor connected in series are provided in parallel with the first switch.

[Brief Description of Drawings]

[0011]

Fig. 1 is a diagram which shows an example of a configuration of a DC circuit breaker 1 according to an embodiment.
Fig. 2 is a diagram which schematically shows an abnormality occurring in a DC system.
Fig. 3 is a diagram which shows a state of the DC circuit breaker 1 in which a mechanical circuit breaker 10 is mechanically controlled to be in an open state.
Fig. 4 is a diagram which shows the state of the DC circuit breaker 1 in which a surge switch 80 is controlled to be in a closed state.
Fig. 5 is a diagram which shows the state of the DC circuit breaker 1 in which a commutation switch 50 is controlled to be in a closed state.
Fig. 6 is a diagram which shows the state of the DC circuit breaker 1 in which the mechanical circuit breaker 10 is electrically controlled to be in an open state.
Fig. 7 is a diagram which shows the state of the DC circuit breaker 1 in which a lightning arrester 15 has operated.
Fig. 8 is a diagram which shows the state of the DC circuit breaker 1 controlled to be a state of charging a commutation capacitor 60.
Fig. 9 is a diagram which shows the state of the DC circuit breaker 1 in which a commutation switch 50 is controlled to be in an open state.
Fig. 10 is a diagram which shows the state of the DC circuit breaker 1 in which a surge switch 80 is controlled to be in an open state.
Fig. 11 is a diagram which shows the state of the DC circuit breaker 1 in which a first disconnector 20 and a second disconnector 30 are controlled to be in an open state.
Fig. 12 is a graph which shows an example of a change over time according to the DC circuit breaker 1.
Fig. 13 is a flowchart which shows an example of an operation of the DC circuit breaker 1.

[Description of Embodiments]

[0012] Hereinafter, a DC circuit breaker of an embodiment will be described with reference to the drawings.

(Embodiment)

[Configuration of DC circuit breaker 1]

[0013] Fig. 1 is a diagram which shows an example of a configuration of a DC circuit breaker 1 of the embodiment. The DC circuit breaker 1 is a device that causes a first DC transmission line LN1 and a second DC transmission line LN2 among DC transmission lines constituting a DC system to be electrically conducted or cut off. In the following description, a DC voltage in the first DC transmission line LN1 will be described as a first voltage VDC1, and a DC voltage in the second DC transmission line LN2 will be described as a second voltage VDC2. The first voltage VDC1 and the second voltage VDC2 are, for example, voltages of about several tens to several hundreds of [kV]. For example, a power transmission facility is present on the first DC transmission line LN1 side, and a consumer is present on the second DC transmission line LN2 side. In this case, the first voltage VDC1 is usually larger than the second voltage VDC2. Therefore, a current of the DC system normally flows in a direction from the first DC transmission line LN1 to the second DC transmission line LN2.

[0014] The DC circuit breaker 1 includes, for example, one or more mechanical circuit breakers 10, one or more disconnectors, a lightning arrester 15, a commutation circuit 40, and a control unit 100. In the present embodiment, a case where the DC circuit breaker 1 includes two disconnectors of a first disconnector 20 and a second disconnector 30 will be described. In the following description, when the first disconnector 20 and the second disconnector 30 are not distinguished, they are simply described as "disconnectors." The commutation circuit 40 includes, for example, a commutation switch 50, a commutation capacitor 60, a commutation reactor 70, a surge switch 80, and a surge resistor 90.

[0015] The control unit 100 receives, for example, a signal (hereinafter, a cut-off instruction signal) indicating that the first DC transmission line LN1 and the second DC transmission line LN2 are electrically cut off from a detection device (not shown) that detects an abnormality of the DC system. When the control unit 100 receives the cut-off instruction signal, it performs control with respect to an open or closed state of the mechanical circuit breaker 10, the first disconnector 20, the second disconnector 30, the commutation switch 50, and the surge switch 80 so as to electrically cut off the first DC transmission line LN1 and the second DC transmission line LN2. The abnormality of the DC system is, for example, an abnormality caused by an accident such as a ground fault or a short circuit occurring in a DC transmission line.

[0016] The mechanical circuit breaker 10 includes a first terminal 10a and a second terminal 10b. The first disconnector 20 includes a first terminal 20a and a second terminal 20b. The second disconnector 30 includes a first terminal 30a and a second terminal 30b. The commutation circuit 40 includes a first terminal 40a and a second terminal 40b. The commutation switch 50 includes a first terminal 50a and a second terminal 50b. The surge switch 80 includes a first terminal 80a and a second terminal 80b.

[0017] The first disconnector 20, the mechanical circuit breaker 10, and the second disconnector 30 are connected in series between the first DC transmission line LN1 and the second DC transmission line LN2 in the order of description. Specifically, the first terminal 10a of the first disconnector 20 is connected to the first DC transmission line LN1, the second terminal 20b of the first disconnector 20 and the first terminal 10a of the mechanical circuit breaker 10 are connected to each other, and the second terminal 10b of the mechanical circuit breaker 10 and the first terminal 30a of the second disconnector 30 are connected to each other, and the second terminal 30b of the second disconnector 30 is connected to the second DC transmission line LN2.

[0018] The lightning arrester 15 and the commutation circuit 40 are connected to the mechanical circuit breaker 10 in parallel with each other. Specifically, the first terminal 10a of the mechanical circuit breaker 10, one end of the lightning arrester 15, and the first terminal 40a of the commutation circuit 40 are connected to each other, and the second terminal 10b of the mechanical circuit breaker 10, the other end of the lightning arrester 15, and the second terminal 40b of the commutation circuit 40 are connected to each other.

[0019] In the commutation circuit 40, the commutation switch 50, the commutation capacitor 60, and the commutation reactor 70 are connected in series between the first terminal 40a and the second terminal 40b in the order of description. Specifically, the first terminal 40a and the first terminal 50a of the commutation switch 50 are connected, and the second terminal 50b of the commutation switch 50 and one end (a positive electrode terminal in Fig. 1) of the commutation capacitor 60 are connected, the other end (a negative electrode terminal in Fig. 1) of the commutation capacitor 60 and one end of the commutation reactor 70 are connected, and the other end of the commutation reactor 70 and the second terminal 40b are connected. In addition, in the commutation circuit 40, the surge switch 80 and the surge resistor 90 are connected in series in the order of description, and connected in parallel to the commutation switch 50. Specifically, the first terminal 80a of the surge switch 80 is connected to the first terminal 50a of the commutation switch 50, the second terminal 80b of the surge switch 80 is connected to one end of the surge resistor 90, and the other end of the surge resistor 90 is connected to the second terminal 50b of the commutation switch 50.

[0020] In the description above, a case where the commutation circuit 40 includes the first terminal 40a and the second terminal 40b has been described, but the present invention is not limited thereto, and the commutation circuit 40 may include the first terminal 40a and the second terminal 40b. In this case, in the configuration described above, respective parts connected via the first terminal 40a and the second terminal 40b are directly connected. In the following description, for convenience of description, it is described that the commutation circuit 40 includes the first terminal 40a and the second terminal 40b.

[0021] The lightning arrester 15 absorbs a surge voltage generated when the mechanical circuit breaker 10 is controlled to be in the closed state. A limited voltage of the lightning arrester 15 is a magnitude of about 1.5 [p.u] when the first voltage VDC1 and the second voltage VDC2 are used as a reference in a state in which the DC system does not have an abnormality such as an accident.

[0022] The commutation switch 50 is, for example, a mechanical switch. Specifically, the commutation switch 50 is a contact method switch that has a pair of electrodes, moves at least one of electrodes to make a distance between the electrodes shorter on the basis of control of the control unit 100, and lowers the insulation performance between the electrodes to below that in an open state to cause dielectric breakdown, thereby making a closed state. The commutation switch 50 is an example of the "first switch."

[0023] The commutation switch 50 may be a non-contact method switch. In this case, the commutation switch 50 has a pair of fixed electrodes, lowers the insulation performance between the electrodes to below that in the open state on the basis of the control of the control unit 100 to cause dielectric breakdown, thereby making the closed state.

[0024] The commutation capacitor 60 is charged such that, for example, a voltage (hereinafter referred to as a capacitor voltage) generated between a positive electrode terminal and a negative electrode terminal by a charging device (not shown) in an initial state match or substantially match the first voltage VDC1 and the second voltage VDC2 in a state in which an abnormality such as an accident in the DC system does not occur. The initial state is, for example, a time when the DC circuit breaker 1 is installed or a time when an operation of the DC circuit breaker 1 is started. The charging device may charge the commutation capacitor 60 by, for example, applying a system voltage of the DC system thereto, or may charge the commutation capacitor 60 by an external power source other than the system voltage of the DC system. The commutation capacitor 60 is, for example, a capacitor having a charging capacity of several to several tens [μF].

[0025] The commutation capacitor 60 and the commutation reactor 70 configure an LC resonant circuit as the commutation switch 50 is controlled to be in the closed state, and resonate the current of the DC system depending on a resonance frequency according to a capacitor component of the commutation capacitor 60 and a resonator component of the commutation reactor 70 to generate a timing at which the current of the DC system becomes 0 [A]. In the following description, the generation of a timing at which the current of the DC system becomes 0 [A] is also described as "creating a zero point." The commutation reactor 70 has a value set according to a capacity of the commutation capacitor 60 so that a reclosing time from a time tg to a time th, which will be described below, does not exceed a maximum value of a reclosing time set in advance while ensuring a predetermined reclosing time.

[0026] The surge switch 80 is, for example, a mechanical switch. The surge switch 80 is an example of the "second switch."

[0027] The surge resistor 90 reduces a surge that occurs as the commutation switch 50 is controlled to be in the closed state by dielectric breakdown in a state where the surge switch 80 is controlled to be in the closed state. The surge resistor 90 is, for example, a resistor having a resistor value of about several hundred to several k [Ω].

[0028] In the following description, each state of the DC circuit breaker 1 will be described with reference to Figs. 2 to 11. In addition, with reference to Fig. 12, a change over time in the open or closed state of each part of the DC circuit breaker 1 or an electrical change over time of each part will be described. Fig. 12 is a graph which shows an example of a change over time according to the DC circuit breaker 1. In Fig. 12, the horizontal axis represents a time. A waveform W10 indicates the open or closed state of the mechanical circuit breaker 10, a waveform W12 indicates the open or closed state of the surge switch 80, a waveform W14 indicates the open or closed state of the commutation switch 50, and a waveform W16 indicates the open or closed state of a disconnector. In the waveforms W10 to W16, "C" represents a closed state (Close), and "O" represents an open state (Open).

[0029] In addition, waveforms W20 to W26 are waveforms that show changes over time in current related to the DC circuit breaker 1, and a vertical axis of the waveforms W20 to W26 shows a magnitude of a current. In the waveforms W20 to W26, a value of the current of the DC system flowing in a direction from the first DC transmission line LN1 to the second DC transmission line LN2 is indicated by a positive value, and a value of the current of the DC system flowing in a direction from the second DC transmission line LN2 to the first DC transmission line LN1 is indicated by a negative value.

[0030] A waveform W20 is a waveform which shows a change in DC current over time. A waveform W22 is a waveform which shows a change over time in current flowing through the mechanical circuit breaker 10. A waveform W24 is a waveform which shows a change over time in current flowing through the commutation capacitor 60. A waveform W26 is a waveform which shows a change over time in current flowing through the lightning arrester 15.

[0031] Waveforms W30 and W32 are waveforms which show changes over time in voltage related to the DC circuit breaker 1, and the vertical axis of the waveforms W30 and W32 shows the magnitude of a voltage. A waveform W30 is a waveform which shows a change over time in voltage applied between electrodes of the mechanical circuit breaker 10. A waveform W34 is a waveform which shows a change over time in voltage of the capacitor.

[From conduction state to occurrence of abnormality]

[0032] As shown in Fig. 1, in a state in which the first DC transmission line LN1 and the second DC transmission line LN2 are electrically conducted by the DC circuit breaker 1 (hereinafter referred to as a conduction state), the control unit 100 controls each part to be a state as follows. In Fig. 12, the conduction state is between times t0 and ta.

- Mechanical circuit breaker 10: closed state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: open state
- Surge switch 80: open state
- Commutation capacitor 60: charged state

[0033] Fig. 2 is a diagram which schematically shows an abnormality generated in the DC system. In Fig. 2, a ground fault accident has occurred in the second DC transmission line LN2, and the second voltage VDC2 has a ground potential. As shown in Fig. 12, the ground fault accident occurs at a time ta. For this reason, as shown by the waveforms W20 to W22, the current of the DC system, and the current flowing through the mechanical circuit breaker 10 hold predetermined values between the time t0 and the time ta, and increase between the time ta and a time at which the commutation circuit 40 operates (to a time td described below).

[After occurrence of abnormality]

[0034] Fig. 3 is a diagram which shows the state of the DC circuit breaker 1 in which the mechanical circuit breaker 10 is mechanically controlled to be in the open state. The detector transmits a cut-off instruction signal to the DC circuit breaker 1 as an abnormality occurs in the DC system. The control unit 100 receives the cut-off instruction signal from the detection device at a time tb, and controls the mechanical circuit breaker 10 to be in the open state. The states of respective parts of the DC circuit breaker 1 at this time are as follows.

- Mechanical circuit breaker 10: mechanically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: open state
- Surge switch 80: open state
- Commutation capacitor 60: charged state

[0035] As shown by the waveform W10 in Fig. 12, the mechanical circuit breaker 10 is controlled to be in the closed state at the time tb, and the electrodes are physically separated from each other. However, even if the electrodes are physically separated from each other, the mechanical circuit breaker 10 is not electrically cut off (that is, it becomes a mechanically open state) because an arc is generated between the electrodes. Therefore, as shown by the waveforms W20 to W22, the current of the DC system and the current flowing through the mechanical circuit breaker 10 also increase between the time tb and a time tc.

[Surge suppression]

[0036] Fig. 4 is a diagram which shows the state of the DC circuit breaker 1 in which the surge switch 80 is controlled to be in the closed state. The control unit 100 controls the surge switch 80 to be in the closed state at the time tc to reduce a surge due to the commutation switch 50 being set to the closed state (refer to Fig. 12). The states of respective parts of the DC circuit breaker 1 at this time are as follows.

- Mechanical circuit breaker 10: mechanically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: open state
- Surge switch 80: closed state
- Commutation capacitor 60: state in which discharging is slightly started

[0037] In Fig. 4, the surge switch 80 is electrically in the conduction state by an arc being generated by causing a dielectric breakdown between electrodes before the surge switch 80 is mechanically controlled to be in the closed state by the control unit 100 and the electrodes are brought into contact with each other. Therefore, a surge is generated by controlling the surge switch 80 to be in the closed state, but this surge is suppressed by the surge resistor 90. In addition, as the surge switch 80 is controlled to be in the closed state, a capacitor voltage of the commutation capacitor 60 charged in advance, the surge resistor 90, and the commutation reactor 70 act on loops of the mechanical circuit breaker 10, the commutation reactor 70, the commutation capacitor 60, the surge resistor 90, and the surge switch 80 in the DC circuit breaker 1, and a minute commutation current L3 starts to flow.

[0038] Since the commutation capacitor 60 is discharged by a flow of this minute commutation current L3, as shown by the waveform W24 in Fig. 12, the current flowing through the commutation capacitor 60 increases slightly between the time tc and the time at which the commutation circuit 40 operates. Moreover, along with this, as shown by a waveform W32, the capacitor voltage of the commutation capacitor 60 slightly decreases between the time tc and the time at which the commutation circuit 40 operates.

[Commutation circuit operation]

[0039] Fig. 5 is a diagram which shows the state of the DC circuit breaker 1 in which the commutation switch 50 is controlled to be in the closed state. The control unit 100 sets the commutation switch 50 to the closed state at a time td and operates the commutation circuit 40 (refer to Fig. 12). As mentioned above, since the surge resistor 90 has already suppressed a surge, even if the commutation switch 50 is controlled to be in the closed state, the surge is not generated, or the surge is sufficiently suppressed to the extent that peripheral circuit elements and other peripheral devices do not malfunction or break down. The states of respective parts at this time are as follows.

- Mechanical circuit breaker 10: mechanically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: closed state
- Surge switch 80: closed state
- Commutation capacitor 60: discharge state

[0040] As the commutation switch 50 is controlled to be in the closed state, in the DC circuit breaker 1, the capacitor voltage of the commutation capacitor 60 charged in advance and the commutation reactor 70 act on the loops of the mechanical circuit breaker 10, the commutation reactor 70, the commutation capacitor 60, and the commutation switch 50, and a larger commutation current L3 than the minute commutation current L3 flowing in the situation of Fig. 4 described above starts to flow. A direction of the commutation current L3 differs depending on a connection direction between the positive electrode terminal and the negative electrode terminal of the commutation capacitor 60, a location of an accident that has occurred in the DC system, and the like. When the direction of the commutation current L3 is the same as a direction in which the current of the DC system flows (that is, the same polarity), a zero point is generated in the commutation current L3 between the time td and a 1/2 to 3/4 cycle of the resonance frequency. In addition, when the direction of the commutation current L3 is different from the direction in which the current of the DC system flows (that is, an opposite polarity), a zero point is generated in the commutation current L3 between the time td and a 1/4 cycle of the resonance frequency. In the present embodiment, a case where the commutation current L3 is a current having the same polarity as the current of the DC system will be described.

[0041] The commutation current L3 that has resonated by a resonance frequency according to a capacitor component of the commutation capacitor 60 and a reactor component of the commutation reactor 70 flows through the mechanical circuit breaker 10 after the time td. Specifically, as shown by the waveform W22 and waveform W24 in Fig. 12, the commutation current L3 less than a 3/4 wave of the resonance frequency flows through the mechanical circuit breaker 10 and the commutation capacitor 60 between the time td and a time te at which the 3/4 cycle of the resonance frequency elapses, and a zero point is generated at a time te. Moreover, as shown by the waveform W32, since the commutation capacitor 60 acts and the commutation current L3 flows, the capacitor voltage decreases between the time td and the time te.

[Electrical cutoff of mechanical circuit breaker 10]

[0042] Fig. 6 is a diagram which shows the state of the DC circuit breaker 1 in which the mechanical circuit breaker 10 is electrically controlled to be in the open state. The control unit 100 electrically controls the mechanical circuit breaker 10 to be in the open state as a zero point is generated in the commutation current L3 flowing through the mechanical circuit breaker 10 at the time te. The control unit 100 electrically controls the mechanical circuit breaker 10 to be in the open state by extinguishing an arc by, for example, gas cutoff or vacuum cutoff as the zero point is generated. In addition, as shown in Fig. 6, as the mechanical circuit breaker 10 is electrically controlled to be in the open state, the current of the DC system flows into the second DC transmission line LN2 from the first DC transmission line LN1 via a route of the first disconnector 20, the commutation switch 50, the commutation capacitor 60, the commutation reactor 70, and the second disconnector 30. The states of respective parts at this time are as follows.

- Mechanical circuit breaker 10: mechanically and electrically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: closed state
- Surge switch 80: closed state
- Commutation capacitor 60: discharge state

[0043] As shown by the waveform W10 in Fig. 12, the arc is extinguished at the time te, and the mechanical circuit breaker 10 is mechanically and electrically controlled to be in the open state after the time te. In addition, as shown by the waveform W30, a transient recovery voltage is generated between the electrodes of the mechanical circuit breaker 10 that is mechanically and electrically controlled to be in the open state, so that a voltage between the electrodes of the mechanical circuit breaker 10 increases between the time te and the time at which the lightning arrester 15 operates (to a time tf described below). Moreover, as shown by the waveform W24, the current of the DC system flows through the commutation capacitor 60 in a charging direction between the time te and the time at which the lightning arrester 15 operates. For this reason, as shown by the waveform W32, the capacitor voltage increases between the time te and the time at which the lightning arrester 15 operates.

[Operation of lightning arrester 15]

[0044] Fig. 7 is a diagram which shows the state of the DC circuit breaker 1 in which the lightning arrester 15 has operated. As described above, since the transient recovery voltage is generated between the electrodes of the mechanical circuit breaker 10 after the time te, the voltage applied between the electrodes of the mechanical circuit breaker 10 (that is, a voltage applied to both ends of the lightning arrester 15). Then, the voltage between the electrodes of the mechanical circuit breaker 10 reaches an operation voltage of the lightning arrester 15, and the lightning arrester 15 operates. As the lightning arrester 15 operates, the current of the DC system flows from the first DC transmission line LN1 to the second DC transmission line LN2 via a route of the first disconnector 20, the lightning arrester 15, and the second disconnector 30. The states of respective parts at this time are as follows.

- Mechanical circuit breaker 10: mechanically and electrically open state
- Lightning arrester 15: operation state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: closed state
- Surge switch 80: closed state
- Commutation capacitor 60: state in which charging or discharging is not substantially performed

[0045] As shown by the waveform W30 in Fig. 12, the voltage between the electrodes of the mechanical circuit breaker 10 reaches the operation voltage of the lightning arrester 15 at the time tf. Then, as shown by the waveform W26, the lightning arrester 15 starts to operate at the time tf and absorbs a recovery voltage. For this reason, as shown by the waveform W26, a current flowing through the lightning arrester 15 that has rapidly increased at the time tf gradually decreases from the time tf to a time tg, and becomes 0 [A] at the time tg. Along with this, as shown by the waveform W20, the current of the DC system gradually decreases between the time tf and the time tg.

[0046] At this time, almost no current of the DC system flows in a direction from the first DC transmission line LN1 to the commutation circuit 40. For this reason, the voltage between the electrodes of the mechanical circuit breaker 10 indicated by the waveform W30 and the capacitor voltage indicated by the waveform W32 hold values at a timing of the time tf between the time tf and the time tg. As shown by the waveform W16, the arc generated between the electrodes of the commutation switch

50 is extinguished between the time tf and the time tg.

[Charging of commutation capacitor 60]

[0047] Fig. 8 is a diagram which shows the state of the DC circuit breaker 1 controlled to be a state of charging the commutation capacitor 60. When the lightning arrester 15 finishes suppressing a recovery voltage, the current of the DC system flows from the first DC transmission line LN1 to the second DC transmission line LN2 via a route of the first disconnector 20, the commutation switch 50, the commutation capacitor 60, the commutation reactor 70, and the second disconnector 30. The states of respective parts at this time are as follows.

- Mechanical circuit breaker 10: mechanically and electrically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: closed state
- Surge switch 80: closed state
- Commutation capacitor 60: charged state

[0048] As shown by the waveform W20 in Fig. 12, the current of the DC system oscillates between the time tg and the time th at which the commutation capacitor 60 finishes a transient oscillation. The oscillation of the current of the DC system is attenuated as the transient oscillation subsides. For this reason, the current of the DC system gradually converges from the time tg to the time th. In addition, as shown by the waveform W24, electricity of the DC system that oscillates due to transient oscillation flows through the commutation capacitor 60. For this reason, as shown by the waveform W32, the capacitor voltage gradually converges to a predetermined voltage while oscillating due to transient oscillation between the time tg and the time th. The predetermined voltage is a voltage that matches with or substantially matches with the first voltage VDC1.

[0049] A period from the time tg to the time th is an example of the reclosing time. The reclosing time is a time from when the first DC transmission line LN1 and the second DC transmission line LN2 are electrically cut off by the DC circuit breaker 1 to when they are electrically conducted again. As described above, a capacity of the commutation capacitor 60 and a value of the commutation reactor 70 are set such that the transient oscillation converges within a range not exceeding a maximum value of the reclosing time set in advance while a predetermined reclosing time is ensured.

[0050] Here, before the capacitor voltage converges to the predetermined voltage, the insulation performance between the electrodes of the commutation switch 50 is recovered, the arc of the commutation switch 50 is cut or the arc is extinguished by a zero point of a current, and thereby the commutation switch 50 may be in the open state. In this case, the commutation capacitor 60 is charged up to a predetermined voltage by the current of the DC system flowing from the first DC transmission line LN1 to the second DC transmission line LN2 via a route of the surge switch 80 and the surge resistor 90.

[Open state of commutation switch 50]

[0051] Fig. 9 is a diagram which shows the state of the DC circuit breaker 1 in which the commutation switch 50 is controlled to be in the open state. The control unit 100 determines whether the capacitor voltage of the commutation capacitor 60 is a predetermined voltage after the time tg. For example, when the transient oscillation of the current of the DC system is converging, the control unit 100 determines that the commutation capacitor 60 has been charged up to a predetermined voltage. When the control unit 100 determines that the commutation capacitor 60 has been charged up to the predetermined voltage, the control unit 100 controls the commutation switch 50 to be in the open state. The states of respective parts at this time are as follows.

- Mechanical circuit breaker 10: mechanically and electrically open state
- Lightning arrester 15: stop state
- First disconnector 20: closed state
- Second disconnector 30: closed state
- Commutation switch 50: open state
- Surge switch 80: closed state
- Commutation capacitor 60: charged state

[0052] As shown by the waveform W20 in Fig. 12, the control unit 100 determines that the commutation capacitor 60 has been charged up to the predetermined voltage at the time th, and controls the commutation switch 50 to be in the open state.

[DC system cutoff]

[0053] Fig. 10 is a diagram which shows the state of the DC circuit breaker 1 in which the first disconnector 20 and the second disconnector 30 are controlled to be in the open state. Fig. 11 is a diagram which shows the state of the DC circuit breaker 1 in which the surge switch 80 is controlled to be in the open state. The control unit 100 controls the first disconnector 20 and the second disconnector 30 to be in the open state after controlling the commutation switch 50 to be in the open state. Then, the control unit 100 controls the surge switch 80 to be in the open state after controlling the first disconnector 20 and the second disconnector 30 to be in the open state. The states of respective parts in a situation of Fig. 11 are as follows.

- Mechanical circuit breaker 10: mechanically and electrically open state
- Lightning arrester 15: stop state
- First disconnector 20: open state

- Second disconnector 30: open state
- Commutation switch 50: open state
- Surge switch 80: open state
- Commutation capacitor 60: charged state

[0054] As shown by the waveform W12 in Fig. 12, the control unit 100 controls the first disconnector 20 and the second disconnector 30 to be in the open state at a time ti. In addition, as shown by the waveform W12, the control unit 100 controls the surge switch 80 to be in the open state at a time tj.

[0055] The control unit 100 may control the first disconnector 20 and the second disconnector 30 to be in the open state after controlling the surge switch 80 to be in the open state, and may control the first disconnector 20 and the second disconnector 30 to be in the open state in order.

[Operation flow]

[0056] Fig. 13 is a flowchart which shows an example of operations of the DC circuit breaker 1. First, the control unit 100 determines whether a cut-off instruction signal indicating that the first DC transmission line LN1 and the second DC transmission line LN2 are electrically cut off is received from the detection device (step S100). The control unit 100 waits until it receives the cut-off instruction signal from the detection device. When the control unit 100 receives the cut-off instruction signal, it controls the mechanical circuit breaker 10 to be in the open state (step S102). Next, the control unit 100 controls the surge switch 80 to be in the closed state (step S104). At this time, a surge generated by controlling the surge switch 80 to be in the closed state is suppressed by the surge resistor 90.

[0057] Next, the control unit 100 controls the commutation switch 50 to be in the closed state (step S106). At this time, since the surge is sufficiently suppressed by the surge resistor 90, even if the commutation switch 50 is in the closed state, the surge is sufficiently suppressed to the extent that a surge is not generated or peripheral circuit elements and other peripheral devices do not malfunction or break down. In addition, as the commutation switch 50 is controlled to be in the closed state, in the DC circuit breaker 1, the capacitor voltage of the commutation capacitor 60 charged in advance and the commutation reactor 70 act on the loops of the mechanical circuit breaker 10, the commutation reactor 70, the commutation capacitor 60, and the commutation switch 50, and the commutation current L3 resonated by a resonance frequency according to the capacitor component of the commutation capacitor 60 and the reactor component of the commutation reactor 70 flows.

[0058] The control unit 100 electrically controls the mechanical circuit breaker 10 to be in the open state as a zero point is generated in the resonant commutation current L3 flowing through the mechanical circuit breaker 10 (step S108). Since a transient recovery voltage is generated between the electrodes of the mechanical circuit breaker 10 by electrically controlling the mechanical circuit breaker 10 to be in the open state, a voltage applied between the electrodes of the mechanical circuit breaker 10 (that is, a voltage applied to both ends of the lightning arrester 15) increases. Then, a voltage between the electrodes of the mechanical circuit breaker 10 reaches the operation voltage of the lightning arrester 15, and the lightning arrester 15 operates (step S110).

[0059] As the lightning arrester 15 operates, the current of the DC system flows from the first DC transmission line LN1 to the second DC transmission line LN2 via the route of the first disconnector 20, the lightning arrester 15, and the second disconnector 30. The current of the DC system oscillates until the commutation capacitor 60 finishes the transient oscillation. The current of the DC system attenuates as the transient oscillation subsides. In addition, since the current of the DC system flows through the commutation capacitor 60 in the charging direction, the capacitor voltage gradually converges to a predetermined voltage while oscillating due to the transient oscillation. The predetermined voltage is a voltage that matches or substantially matches a DC voltage supplied by the DC system such as the first DC transmission line LN1 and the second DC transmission line LN2.

[0060] The control unit 100 determines whether the capacitor voltage of the commutation capacitor 60 is a predetermined voltage (step S112). For example, when the transient oscillation of the current of the DC system is converging, the control unit 100 determines that the commutation capacitor 60 is charged up to a predetermined voltage. The control unit 100 waits until the commutation capacitor 60 is charged to a predetermined voltage. When the control unit 100 determines that the commutation capacitor 60 is charged up to a predetermined voltage, the control unit 100 controls the commutation switch 50 to be in the open state (step S114). Next, the control unit 100 controls the disconnector to be in the open state (step S 116). Next, the control unit 100 controls the surge switch 80 to be in the open state (step S 118). As a result, the DC circuit breaker 1 can electrically cut off the first DC transmission line LN1 and the second DC transmission line LN2.

[Summary of embodiment]

[0061] As described above, the DC circuit breaker 1 of the embodiment has the mechanical circuit breaker 10, the lightning arrester 15, and the commutation circuit 40. The mechanical circuit breaker 10 has the first terminal 10a connected to the first DC transmission line LN1 via the first disconnector 20, and the second terminal 10b connected to the second DC transmission line LN2 via the second disconnector 30. The commutation circuit 40 has the commutation switch 50, the commutation capacitor 60, the commutation reactor 70, the surge switch 80, and the surge resistor 90. The commutation circuit 40, the lightning arrester 15, and the mechanical circuit breaker 10 are connected in parallel between the first DC transmission line LN1 and the second DC transmission line LN2. The commutation switch 50, the commutation capacitor 60, and the commutation reactor 70 are connected in series between the first DC transmission line LN1 and the second DC transmission line LN2. A surge switch 80 and a surge switch 80 connected in series are provided in parallel with the commutation switch 50.

[0062] Here, when a series circuit of the surge switch 80 and the surge resistor 90 is not provided in parallel with the commutation switch 50, before the capacitor voltage converges to a predetermined voltage, the insulation performance between the electrodes of the commutation switch 50 may be recovered, and the commutation switch 50 may be in the open state. Next, when the commutation switch 50 is in the open state before the capacitor voltage converges to the predetermined voltage, the commutation capacitor 60 may not be charged with power for causing a sufficient commutation current L3 to flow when the first DC transmission line LN1 and the second DC transmission line LN2 are cut off, or the commutation capacitor 60 may be overcharged with power for causing an excessive commutation current L3 to flow.

[0063] When the capacitor voltage is larger than a voltage of the DC system (that is, the commutation capacitor 60 is overcharged), a resonant commutation current L3 becomes large and there is a possibility that a current change rate (di/dt) at a zero point of a current flowing through the mechanical circuit breaker 10 during a period from the time td to the time te will increase. Depending on the performance of the mechanical circuit breaker 10, for the commutation current L3, which has a large current change rate (di/dt), the mechanical circuit breaker 10 cannot be electrically set to the open state, and there is a possibility that a cutoff of the first DC transmission line LN1 and the second DC transmission line LN2 will fail.

[0064] On the other hand, when the capacitor voltage is smaller than the voltage of the DC system (that is, the commutation capacitor 60 is insufficiently charged), a resonant commutation current L3 at a time of reclosing becomes smaller, a zero point by the commutation current L3 flowing through the mechanical circuit breaker 10 cannot be generated, and there is a possibility that the cutoff of the first DC transmission line LN1 and the second DC transmission line LN2 will fail.

[0065] According to the DC circuit breaker 1 of the embodiment, by providing the series circuit of the surge switch 80 and the surge resistor 90 in parallel with the commutation switch 50, even if a current between the electrodes of the commutation switch 50 is cut off or an arc is extinguished at the zero point of the current, the current of the DC system continues to flow through the surge switch 80 and the surge resistor 90 in the commutation capacitor 60, so that the commutation capacitor 60 can be reliably charged up to a predetermined voltage. Therefore, the DC circuit breaker 1 of the present embodiment can appropriately perform reclosing while suppressing a surge.

[0066] Although the embodiment of the present invention has been described, the embodiment is presented as an example and is not intended to limit the scope of the invention. The embodiment can be implemented in various other embodiments, and various omissions, replacements, and changes can be made within a range not departing from the gist of the invention. The embodiment and variations thereof are included in the scope of the invention described in the claims and the equivalent scope thereof, as are included in the scope and gist of the invention.

[Reference Signs List]

[0067]

1 DC circuit breaker
10 Mechanical circuit breaker
10a, 20a, 30a, 40a, 50a, 80a First terminal
10b, 20b, 30b, 40b, 50b, 80b Second terminal
15 Lightning arrester
20 First disconnector
30 Second disconnector
40 Commutation circuit
50 Commutation switch
60 Commutation capacitor
70 Commutation reactor
80 Surge switch
90 Surge resistor
100 Control unit
L3 Commutation current
LN1 First DC transmission line
LN2 Second DC transmission line

Claims

1. A DC circuit breaker comprising:

a mechanical circuit breaker that has a first end connected to a first DC transmission line and a second end connected to a second DC transmission line;
a lightning arrester; and
a commutation circuit that has a first switch, a second switch, a reactor, a capacitor, and a resistor,
wherein the commutation circuit, the lightning arrester, and the mechanical circuit breaker are connected to each other in parallel between the first DC transmission line and the second DC transmission line,
the first switch, the capacitor, and the reactor are connected to each other in series between the first DC transmission line and the second DC transmission line, and
the second switch and the resistor connected in series are provided in parallel with the first

switch.

2. The DC circuit breaker according to claim 1, further comprising:

a control unit configured to control an open or closed state of the first switch,
wherein the first switch is a non-contact method switch that has a pair of fixed electrodes, and
the control unit controls the non-contact method switch to be in a closed state by lowering insulation performance between the electrodes to below that in an open state and causing dielectric breakdown.

3. The DC circuit breaker according to claim 1, further comprising:

a control unit configured to control an open or closed state of the first switch,
wherein the first switch is a contact method switch that has a pair of electrodes, and
the control unit controls the contact method switch to be in a closed state by moving at least one of the electrodes to make a distance between the electrodes shorter, and lowering insulation performance between the electrodes to below that in an open state to cause dielectric breakdown.

4. The DC circuit breaker according to claim 3, wherein, when at least one of the electrodes is moved, the control unit does not bring the electrodes into contact with each other but moves the at least one electrode to a position separated from the electrodes by a predetermined distance.

5. The DC circuit breaker according to any one of claims 1 to 4,
wherein the capacitor is charged by applying a system voltage of a DC system supplied to the first DC transmission line or the second DC transmission line.

6. The DC circuit breaker according to any one of claims 1 to 4,
wherein the capacitor is charged by applying a voltage, which is a voltage supplied from another device, and is equivalent to the system voltage of the DC system supplied to the first DC transmission line or the second DC transmission line.

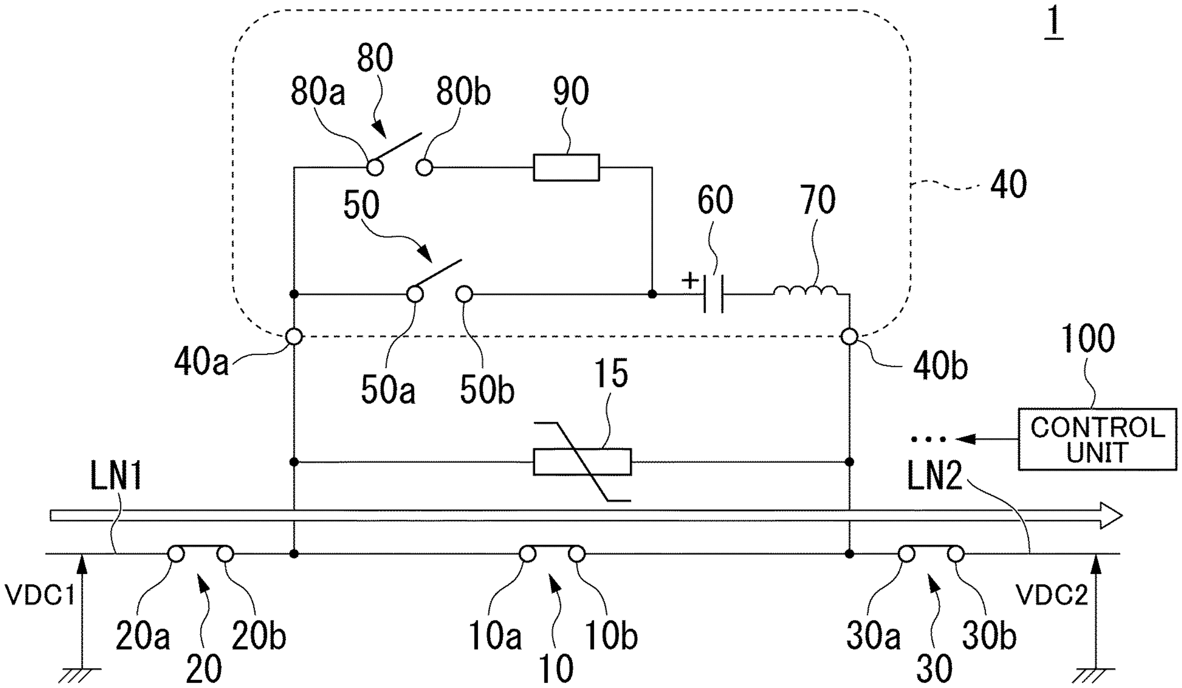
7. The DC circuit breaker according to any one of claims 1 to 6, further comprising:

a control unit configured to control an open or closed state of the first switch,
wherein the reactor and the capacitor resonate a system current of a DC system supplied to the first DC transmission line or the second DC transmission line according to a resonance frequency to generate a zero point in the system current as the control unit controls the first switch to be in a closed state.

8. The DC circuit breaker according to any one of claims 1 to 7, further comprising:

a control unit configured to control an open or closed state of the mechanical circuit breaker, the first switch, and the second switch,
wherein the control unit performs
starting control for setting the mechanical circuit breaker to an open state to electrically cut off the first end and the second end,
controlling the second switch to be in a closed state after control for setting the mechanical circuit breaker to an open state is started,
controlling the first switch to be in a closed state after the second switch is controlled to be in a closed state,
cutting off electrically the first end and the second end of the mechanical circuit breaker at a zero point generated by the reactor and the capacitor resonating a system current of a DC system supplied to the first DC transmission line or the second DC transmission line according to a resonance frequency after the first switch is controlled to be in a closed state,
controlling the second switch to be in an open state when a voltage of the capacitor is a voltage equivalent to the system voltage of the DC system,
controlling the first switch to be in an open state after the second switch is controlled to be in an open state, and
limiting, by the lightning arrester, a voltage generated between the first end and the second end as the mechanical circuit breaker is electrically cut off.

FIG. 1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LN2
VDC1
VDC2
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20b
20
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30b
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FIG. 2

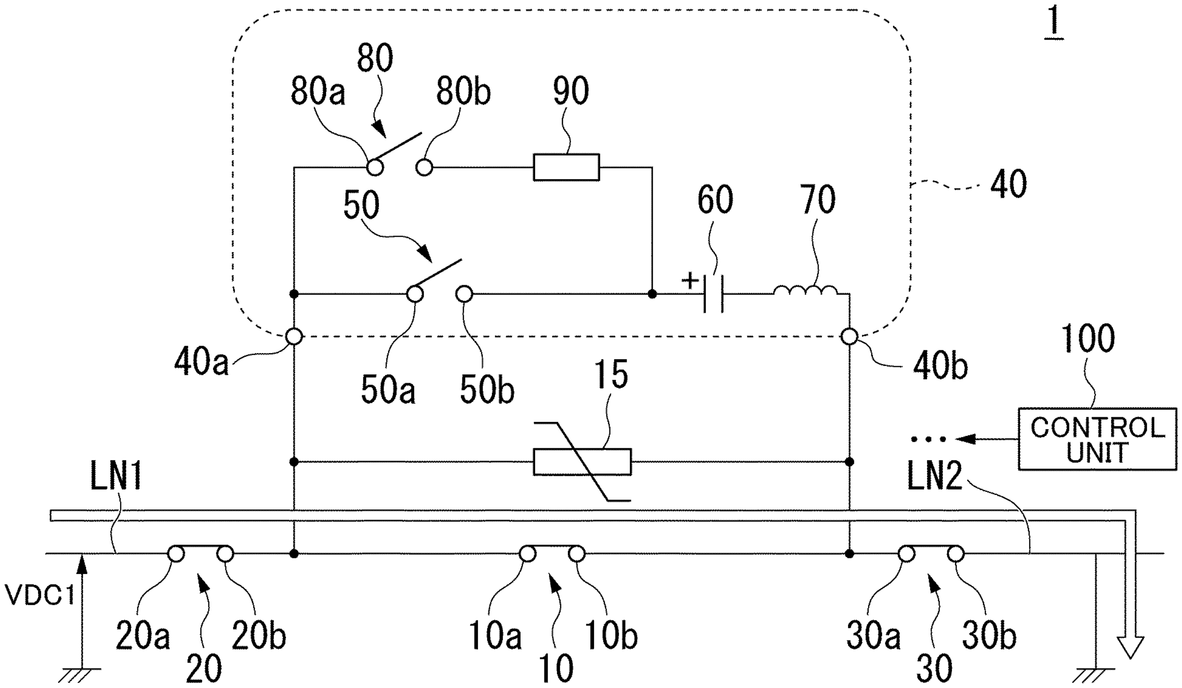
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FIG. 3

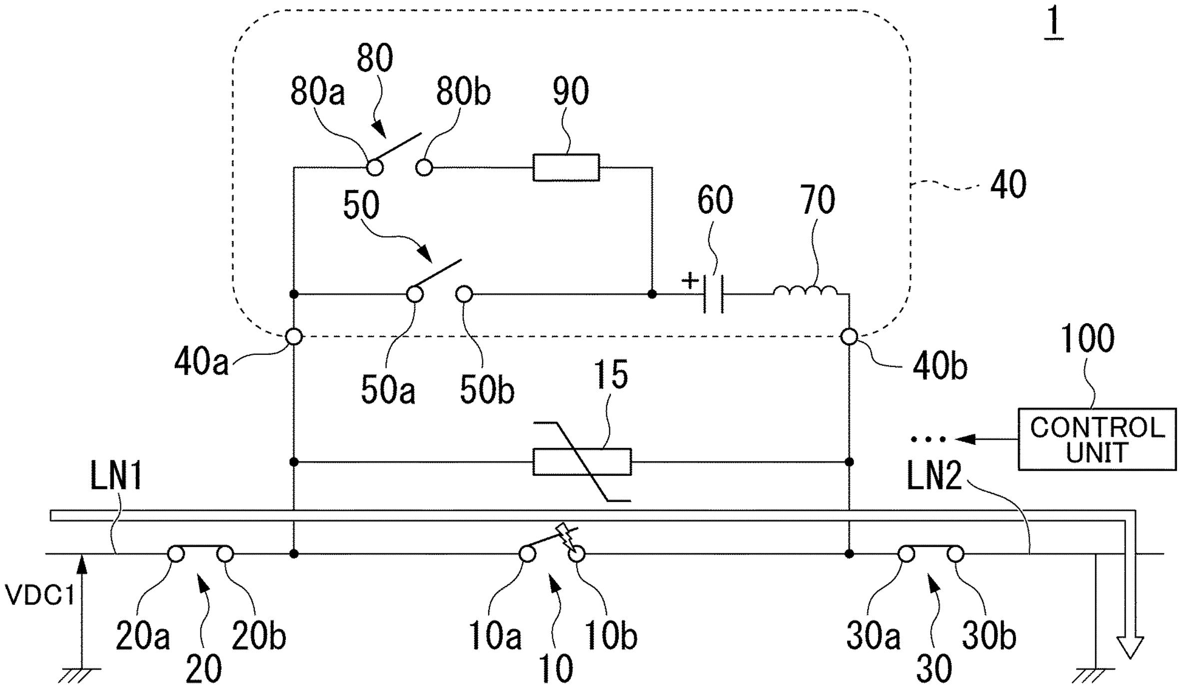
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FIG. 4

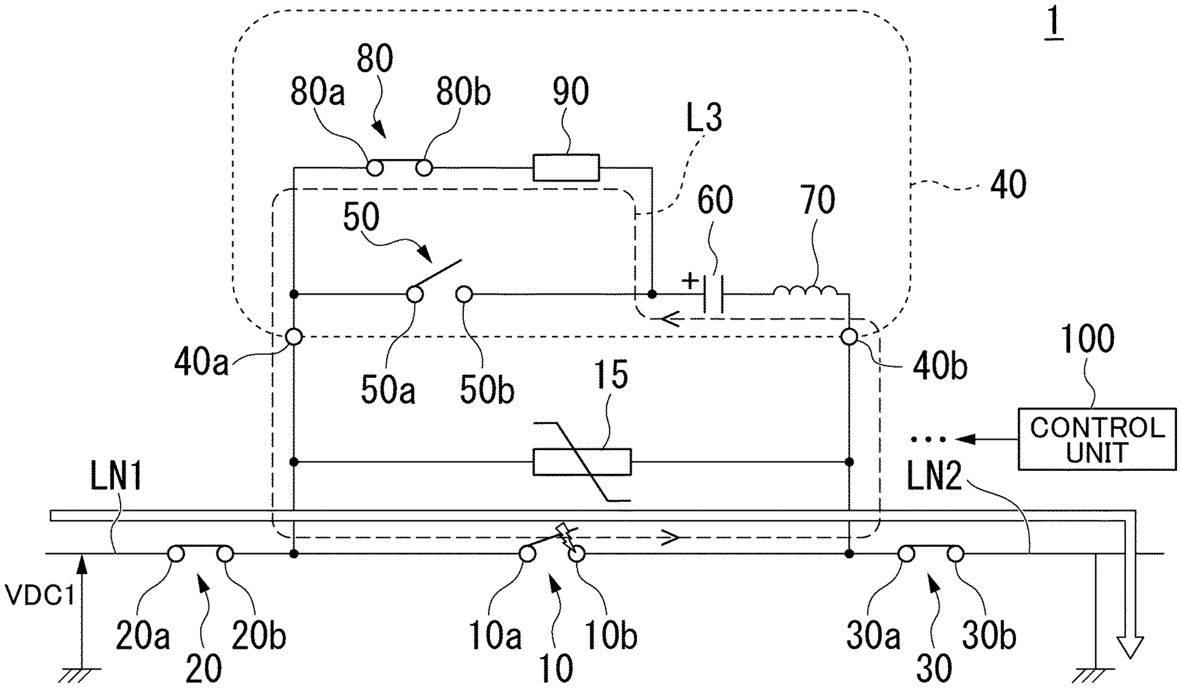
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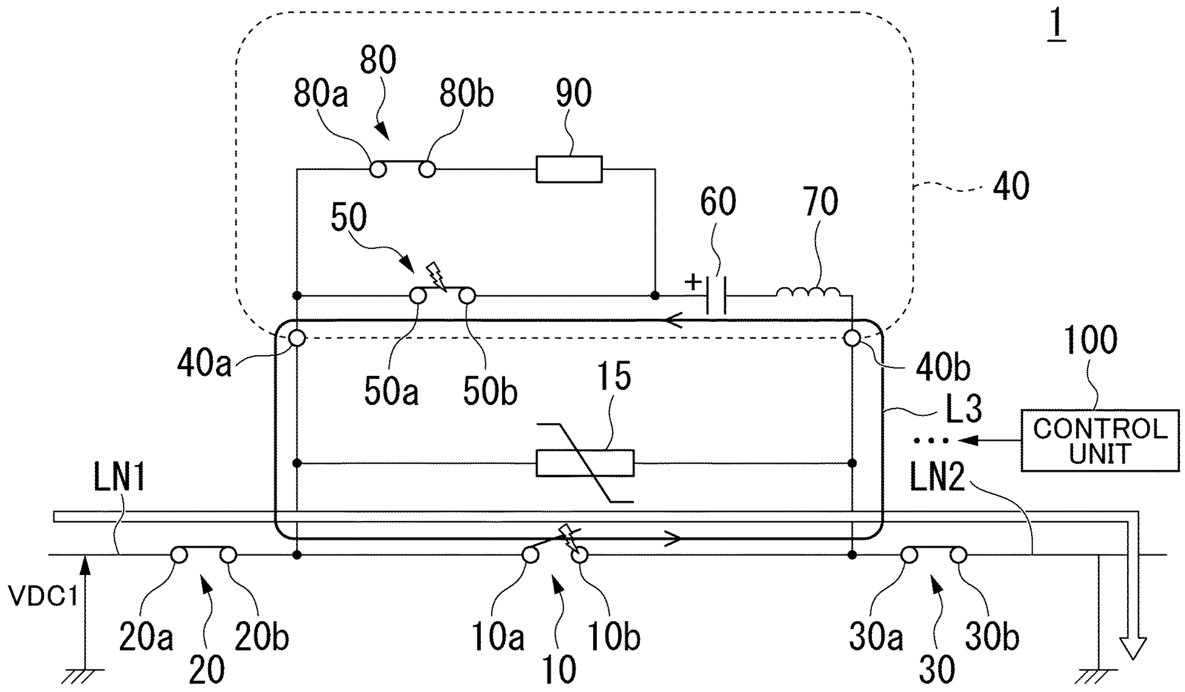
FIG. 5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20b
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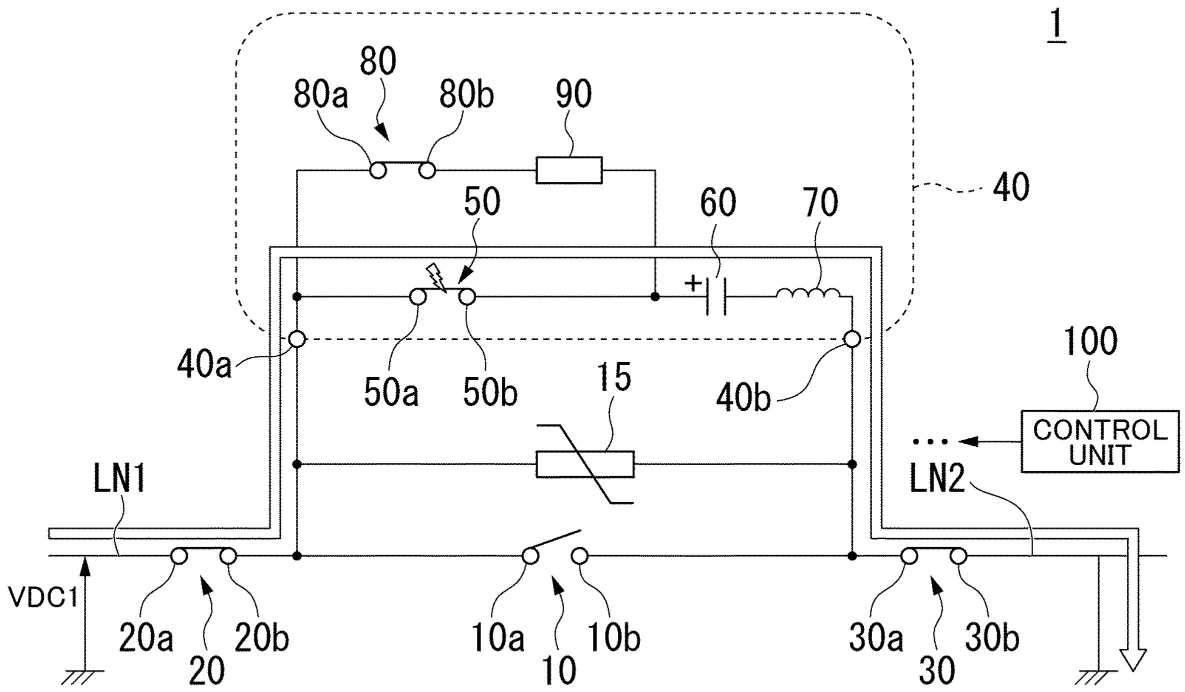
10b
10
30a
30b
30

FIG. 6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30b
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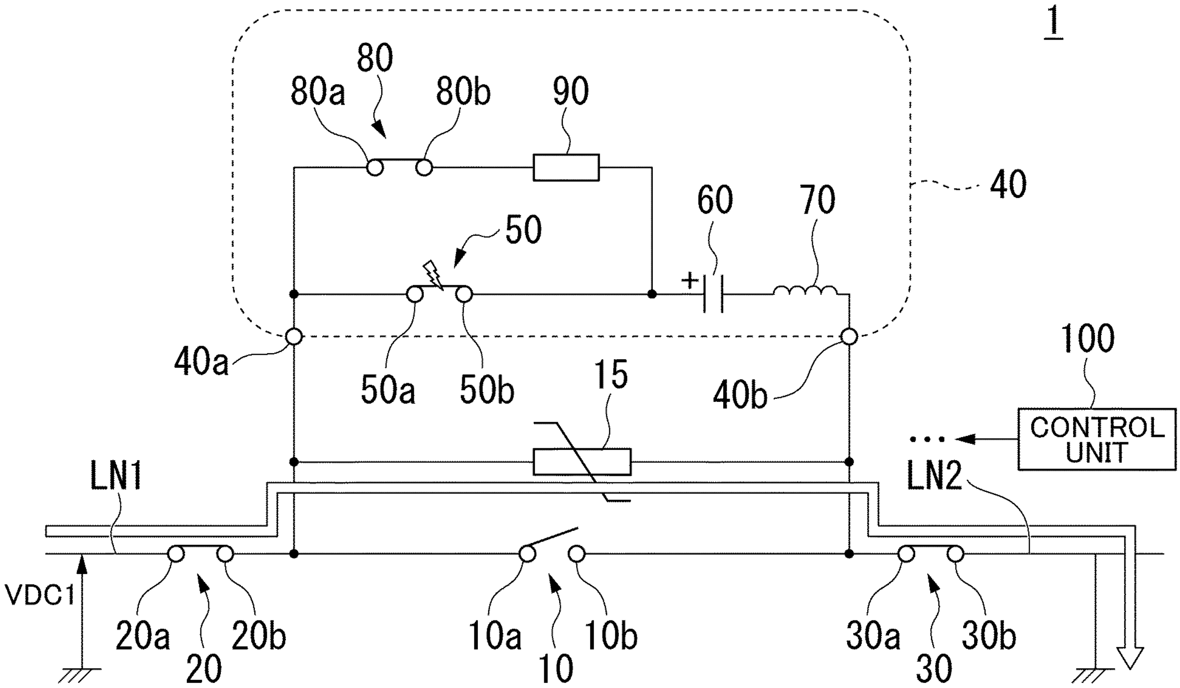
FIG. 7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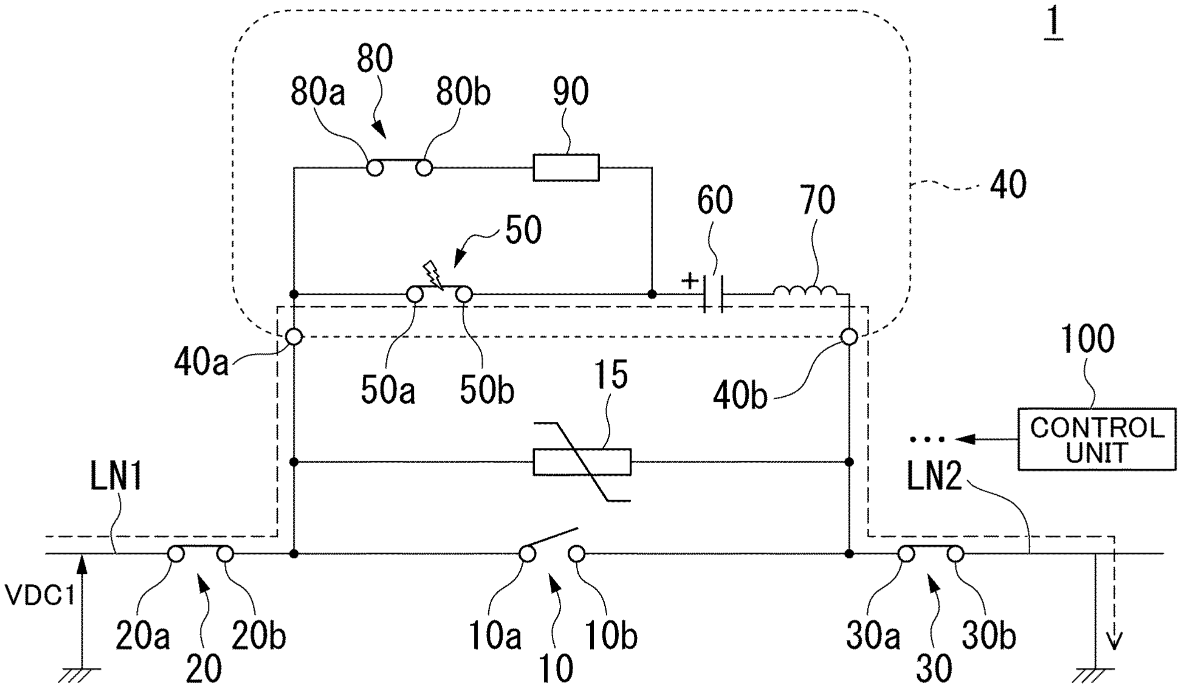
30
30b

FIG. 8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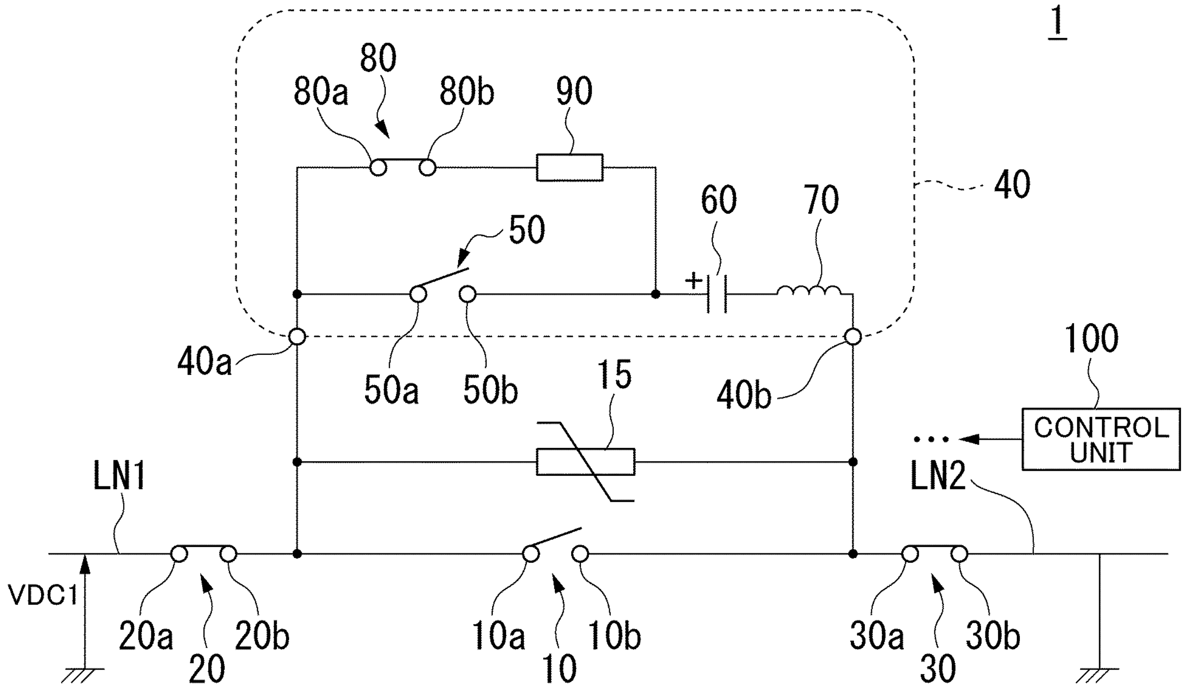
30
30b

FIG. 9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VDC1
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20b
10a
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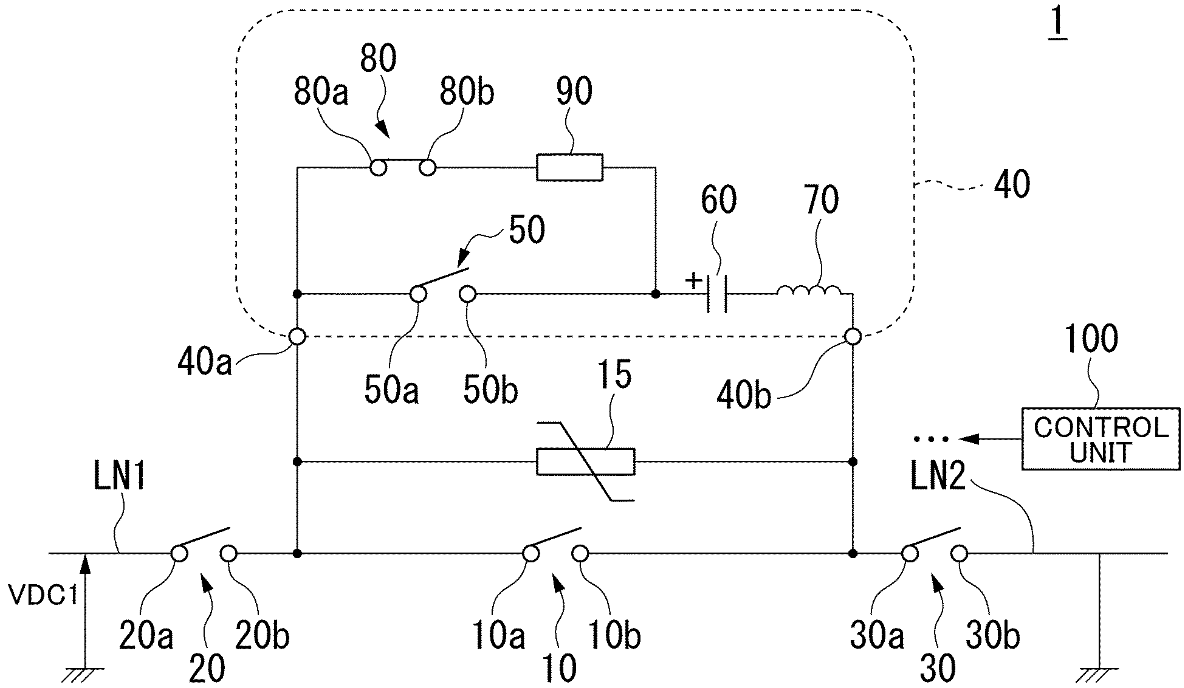
30
30b

FIG. 10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VDC1
20a
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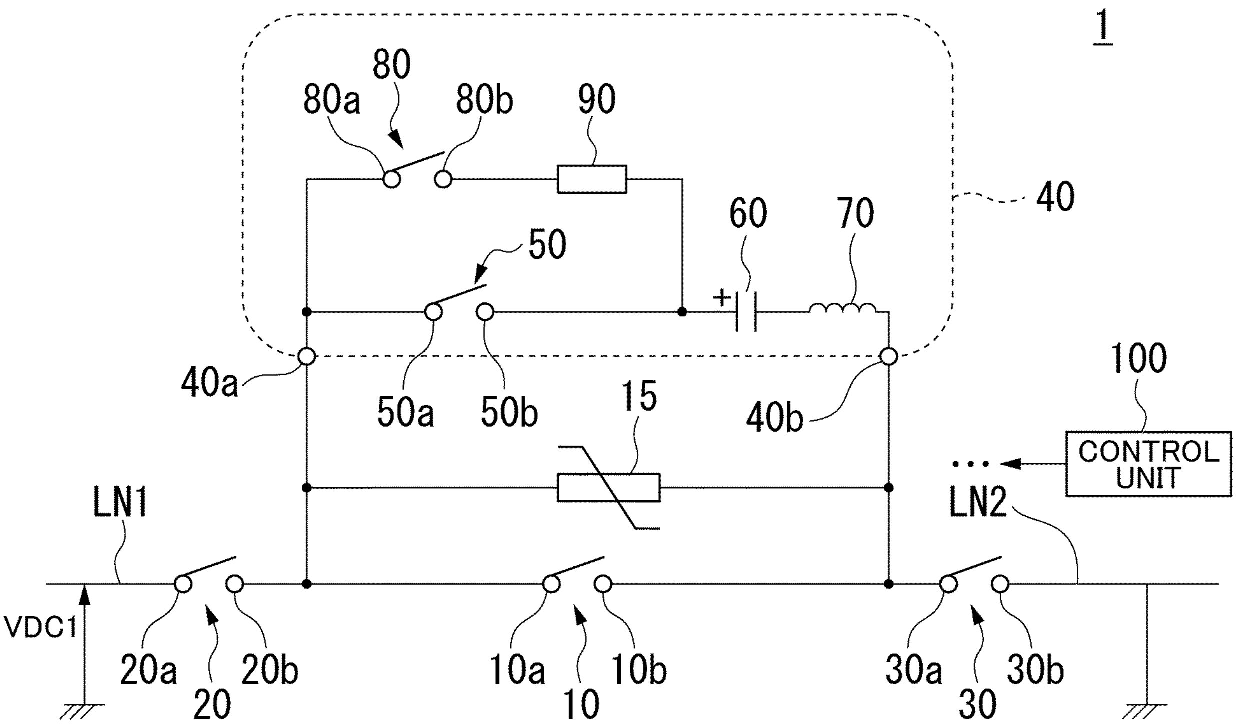
20b
10a
10
10b
30a
30
30b

FIG. 11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LN2
VDC1
20a
20
20b
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10
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30a
30
30b

FIG. 12

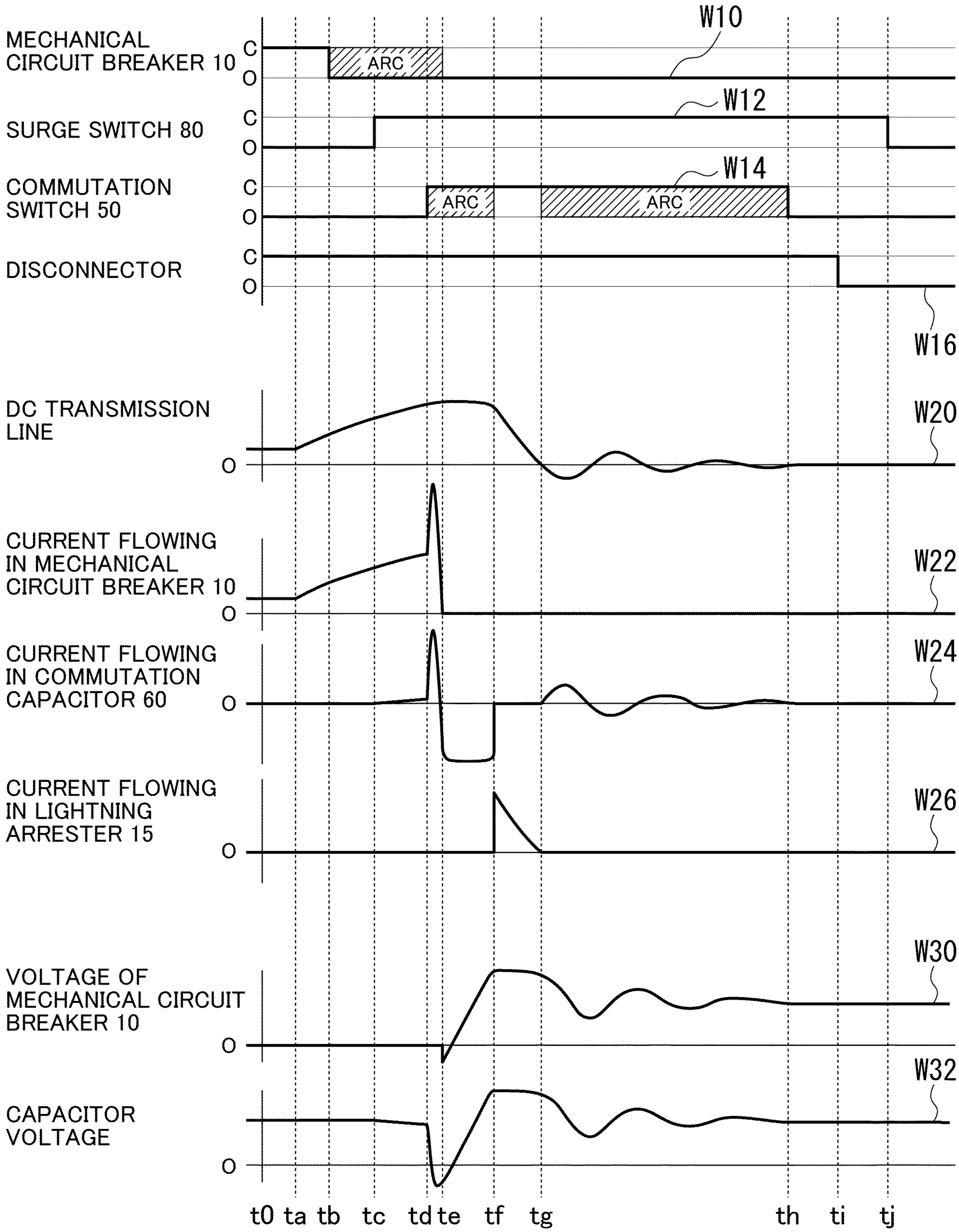
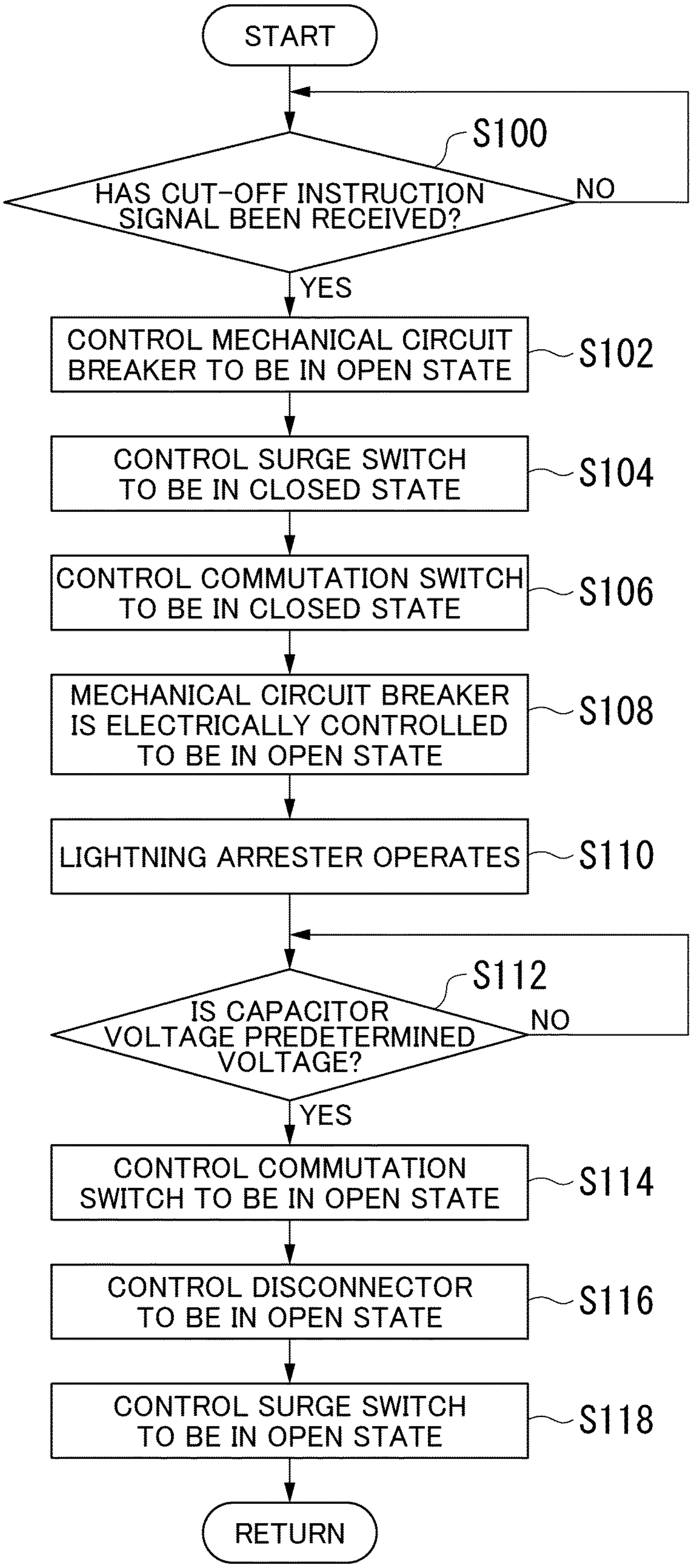

MECHANICAL CIRCUIT BREAKER 10
SURGE SWITCH 80
COMMUTATION SWITCH 50
DISCONNECTOR
C
O
ARC
W10
W12
W14
W16
DC TRANSMISSION LINE
CURRENT FLOWING IN MECHANICAL CIRCUIT BREAKER 10
CURRENT FLOWING IN COMMUTATION CAPACITOR 60
CURRENT FLOWING IN LIGHTNING ARRESTER 15
W20
W22
W24
W26
VOLTAGE OF MECHANICAL CIRCUIT BREAKER 10
CAPACITOR VOLTAGE
W30
W32
t0 ta tb tc td te tf tg th ti tj

FIG. 13


START
S100
HAS CUT-OFF INSTRUCTION SIGNAL BEEN RECEIVED?
NO
YES
CONTROL MECHANICAL CIRCUIT BREAKER TO BE IN OPEN STATE
S102
CONTROL SURGE SWITCH TO BE IN CLOSED STATE
S104
CONTROL COMMUTATION SWITCH TO BE IN CLOSED STATE
S106
MECHANICAL CIRCUIT BREAKER IS ELECTRICALLY CONTROLLED TO BE IN OPEN STATE
S108
LIGHTNING ARRESTER OPERATES
S110
S112
IS CAPACITOR VOLTAGE PREDETERMINED VOLTAGE?
NO
YES
CONTROL COMMUTATION SWITCH TO BE IN OPEN STATE
S114
CONTROL DISCONNECTOR TO BE IN OPEN STATE
S116
CONTROL SURGE SWITCH TO BE IN OPEN STATE
S118
RETURN

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/046772

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. H01H33/59(2006.01)i
FI: H01H33/59 F

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int. Cl. H01H33/59

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2005-197114 A (TOSHIBA CORP.) 21 July 2005, entire text, all drawings	1-8
A	JP 2009-181908 A (TOSHIBA MITSUBISHI-ELECTRIC INDUSTRIAL SYSTEMS CORP.) 13 August 2009, entire text, all drawings	1-8
A	JP 56-152125 A (TOKYO SHIBAURA ELECTRIC CO., LTD.) 25 November 1981, entire text, all drawings	1-8
A	WO 2016/056274 A1 (MITSUBISHI ELECTRIC CORP.) 14 April 2016, entire text, all drawings	1-8

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03.02.2020	10.02.2020

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2019/046772

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
JP 2005-197114 A	21.07.2005	(Family: none)	
JP 2009-181908 A	13.08.2009	(Family: none)	
JP 56-152125 A	25.11.1981	US 4419552 A entire text, all drawings	
WO 2016/056274 A1	14.04.2016	US 2017/0271100 A1 entire text, all drawings EP 3206217 A1	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2015166600 A **[0008]**