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(54) **DIRECT-CURRENT INTERRUPTION DEVICE**

(57) A DC breaker 1 includes a mechanical disconnection switch 2 provided at a power transmission line 100, a mechanical circuit breaker 20 connected in series to the mechanical disconnection switch 2, and a parallel circuit 3 connected in parallel with the mechanical disconnection switch 2 and the mechanical circuit breaker 20. The parallel circuit 3 includes a semiconductor circuit breaker 4 that changes a supply or a breaking of the current from the power transmission line 100 to the parallel circuit 3, and a reactor 55 connected in series to the semiconductor circuit breaker 4. An H-bridge circuit 5 which connects one point between the mechanical disconnection switch 2 and the mechanical circuit breaker 20 to one point between the semiconductor circuit breaker 4 and the reactor 55 is provided. The H-bridge circuit 5 includes an H-bridge unit 50 including a plurality of switching elements 51 and a capacitor 53. The H-bridge circuit 5 controls the current flowing through the mechanical circuit breaker 20 by an output voltage control.

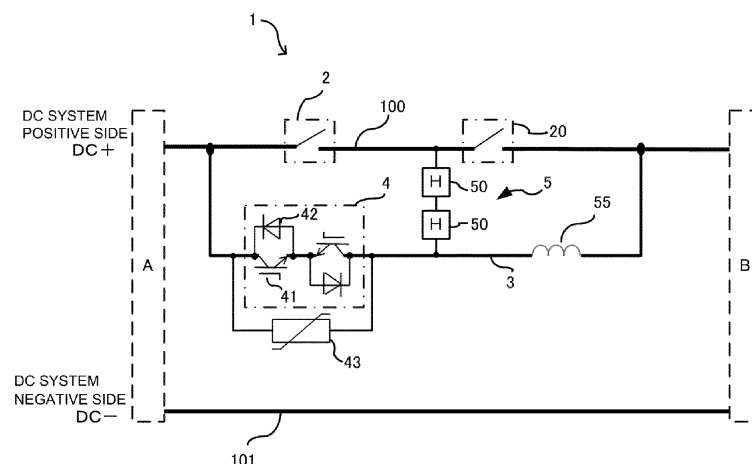


FIG. 1 (a)

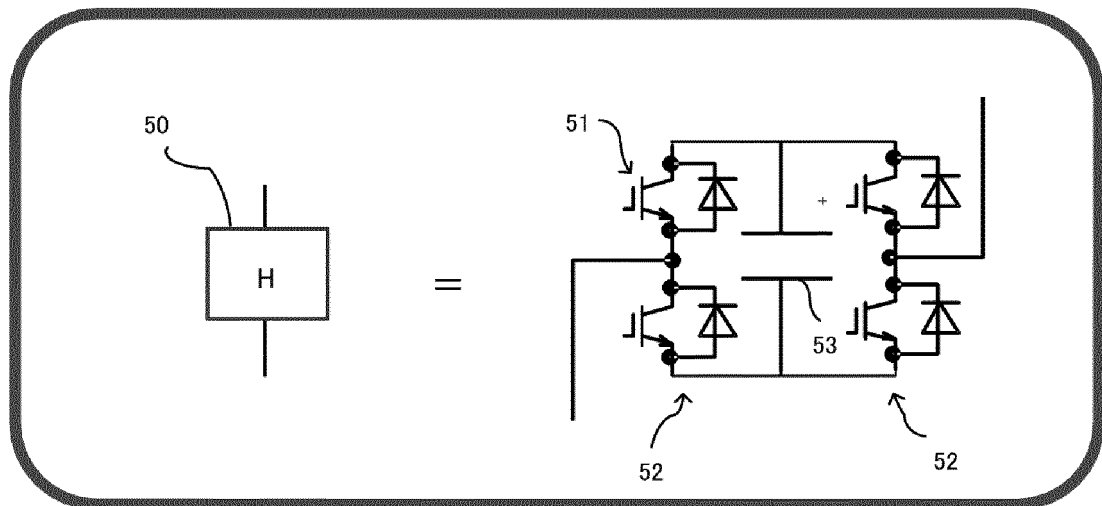


FIG. 1 (b)

DescriptionFIELD

[0001] Embodiments of the present disclosure relate to a DC breaker that disconnects a fault point in a DC power transmission system.

BACKGROUND

[0002] The popularization of renewable energy, such as wind power generation and solar power generation, is advancing in view of load reduction to environment and diversification of power supply. In addition, scale increase of those power supplies is advancing, and for example, wind power generation on ocean sites, solar power generation or solar thermal power generation in desert locations, etc., are becoming in practice. Ocean and desert are often geographically distant from urban areas that are power demanding locations, and power transmission distance becomes long. As for such long-distance power transmission, instead of the AC power transmission systems generally applied, high-voltage direct current power transmission (HVDC) may be applied.

[0003] HVDC can build a system with few power transmission loss at low costs in comparison with conventional AC power transmission systems when applied to long-distance and large power transmission. According to HVDC, however, when a system fault due to lightning strike, etc., occurs, it is difficult to disconnect a fault point. That is because, in the case of AC, a current can be broken at a point where the current traverses zero per a half cycle of 50 Hz or 60 Hz, but in the case of DC, there is no point where the current traverses zero. Hence, even if the contact of a breaker provided in the system is simply disconnected, an arc is produced between the contacts, and the current still flows.

[0004] Hence, a fast-speed breaking has been proposed by applying a semiconductor circuit breaker instead of a mechanical disconnection switch. When, however, a semiconductor circuit breaker is connected in series to a power transmission system, a conduction loss may occur, causing a reduction of power transmission efficiency. Hence, a DC breaker employing a structure that has the semiconductor circuit breaker connected in parallel with the mechanical circuit breaker has been proposed. An H-bridge circuit including a plurality of switching elements and a capacitor are connected in series to the semiconductor circuit breaker. At the time of a fault, the H-bridge circuit is utilized to perform an output voltage control to guide a current to a parallel circuit, and the semiconductor circuit breaker performs fast-speed current breaking.

CITATION LISTPATENT LITERATURES

5 **[0005]** Patent Document 1: JP 2014-235834 A

SUMMARY

10 **[0006]** According to the above DC breaker provided with a parallel circuit, since the current passes through only the mechanical disconnection switch at normal times, a conduction loss by the semiconductor circuit breaker can be avoided. However, the semiconductor circuit breaker provided in the parallel circuit eventually needs to break the fault current which increases along with time, and the semiconductor circuit breaker with a large-current capacity is required. In addition, the H-bridge circuit provided in the parallel circuit also needs to be formed by a same semiconductor element which has the large-current capacity as that of the semiconductor circuit breaker, and there is a possibility in an increase of a facility dimension and costs.

15 **[0007]** Embodiments have been made in view of the foregoing technical problems, and an objective is to provide a DC breaker which is capable of reducing a facility dimension and a conduction loss and is highly efficient and low cost, while having a function of breaking a fault current at fast speed.

20 **[0008]** In order to achieve the above objective, a DC breaker according to an embodiment includes:

a mechanical disconnection switch provided in a DC power transmission system;

a mechanical circuit breaker provided in the DC power transmission system, and connected in series to the mechanical disconnection switch;

a parallel circuit which is connected in parallel with the mechanical disconnection switch and the mechanical circuit breaker, and which includes a semiconductor circuit breaker that changes a supply or a breaking of a current of the DC power transmission system, and a reactor connected in series to the semiconductor circuit breaker; and

an H-bridge circuit that controls a current flowing through the mechanical circuit breaker by an output voltage control, and includes an H-bridge unit which connects one point between the mechanical disconnection switch and the mechanical circuit breaker to one point between the semiconductor circuit breaker and the reactor, and which includes a plurality of switching elements and a capacitor.

BRIEF DESCRIPTION OF DRAWINGS

55 **[0009]**

FIG. 1(a) is a diagram illustrating a structure of a DC breaker according to a first embodiment, and FIG.

1(b) is a diagram illustrating a structure of an H bridge unit;
 FIG. 2 is a diagram illustrating a normal operation of the DC breaker according to the first embodiment;
 FIG. 3 is a diagram for explaining a current operation when a fault occurs;
 FIG. 4 is a diagram illustrating an initial operation of the DC breaker when a fault occurs according to the first embodiment;
 FIG. 5 is a diagram illustrating an intermediate operation of the DC breaker when the fault occurs according to the first embodiment;
 FIG. 6 is a diagram illustrating a latter operation of the DC breaker when the fault occurs according to the first embodiment; and
 FIG. 7 is a diagram illustrating a structure of a DC breaker according to a second embodiment.

DETAILED DESCRIPTION

[0010] A DC breaker according to an embodiment will be described with reference to the figures. Note that, in the description of the embodiment, "normal time" means a state in which a normal current is flowing in a DC power transmission system, and "fault" means a state in which an excessive fault current is caused due to a system fault originating from lightning strike, etc.

(First Embodiment)

(Structure)

[0011] As illustrated in Fig. 1, in a DC power transmission system, power transmission lines which connect two DC power transmission networks A and B are provided. There are a positive side 100 and a negative side 101 in the power transmission lines, and a DC breaker 1 according to this embodiment is provided at the positive side. According to this embodiment, in the positive-side power transmission line 100, an example case in which power is transmitted from the DC power transmission network A to the DC power transmission network B is mainly described.

[0012] The DC breaker 1 includes a mechanical disconnection switch 2 and a mechanical circuit breaker 20 connected in series to the power transmission line 100, a parallel circuit 3 connected in parallel with the mechanical disconnection switch 2 and the mechanical circuit breaker 20, and an H-bridge circuit 5 that connects the power transmission line 100 with the parallel circuit 3. More specifically, the parallel circuit 3 includes a semiconductor circuit breaker 4 and a reactor 55 connected in series to the semiconductor circuit breaker 4, and an arrester 43 is connected in parallel with only the semiconductor circuit breaker 4. In addition, the H-bridge circuit 5 is configured to connect one point of the power transmission line 100 between the mechanical disconnection switch 2 and the mechanical circuit breaker 20,

and one point of the parallel circuit 3 between the semiconductor circuit breaker 4 and the reactor 55.

[0013] Various well-known structures are applicable as the mechanical disconnection switch 2. In this embodiment, since a DC current is broken using the parallel circuit 3 as described later, the mechanical disconnection switch 2 itself does not need a current breaking capability. A mechanical disconnection switch 2 may be utilized as long as it has a mechanical contact and has an insulation withstand voltage against a DC voltage necessary for disconnecting a fault point with the state the contacts is disconnected. The mechanical disconnection switch 2 may employ a structure in which a rotating contactor is provided between terminals of a circuit, and disconnects the circuit by rotating this rotating contactor so as to contact or be apart from a stationary contactor attached to each terminal.

[0014] The mechanical disconnection switch 2 is controlled to be in an ON state, that is, a state in which the contacts are in contact with each other in normal time. A current from the DC power transmission network A passes through the mechanical disconnection switch 2, and flows into the DC power transmission network B. As described later, at the time of a fault, a control is performed so as the current flows into the parallel circuit 3, the state is changed to an OFF state when the current flowing through the mechanical disconnection switch 2 becomes substantially zero, and the circuit is disconnected.

[0015] Various well-known structures are applicable as the mechanical circuit breaker 20. A mechanical circuit breaker 20 may be utilized as long as it has a mechanical contact and has a capability of breaking a small current by opening the contact. The mechanical circuit breaker 20 may employ a structure in which a rotating contactor is provided between the terminals of a circuit, and break the small current by rotating this rotating contactor rotates so as to contact or be apart from a stationary contactor attached to each terminal.

[0016] The mechanical circuit breaker 20 is controlled so as to be in an ON state, that is, a state in which contacts are in contact with each other in normal time. The current from the DC power transmission network A passes through the mechanical disconnection switch 2 and the mechanical circuit breaker 20, and flows into the DC power transmission network B. When a fault occurs, the current flowing in the mechanical circuit breaker 20 increases. The mechanical circuit breaker 20 includes a current sensor (unillustrated). The current flowing through the mechanical circuit breaker 20 is measured by the current sensor, and is compared with a threshold indicating a fault to detect the fault. As described later in detail, at the time of a fault, a control is performed so as the current flows into the H-bridge circuit 5, and the current flowing through the mechanical circuit breaker 20 becomes substantially zero. The mechanical circuit breaker 20 is changed to the OFF state when the flowing current becomes substantially zero, and the circuit is disconnected.

[0017] The parallel circuit 3 connected in parallel with

the mechanical disconnection switch 2 and the mechanical circuit breaker 20 includes the semiconductor circuit breaker 4. The semiconductor circuit breaker 4 includes a plurality of switching elements 41 connected in series, and a diode 42 is connected in reverse parallel to each of the switching elements 41. The semiconductor circuit breaker 4 in the example in FIG. 1 includes two switching elements 41. Example switching element 41 applied is an element having a self-arc-extinguishing ability, such as an IGBT (Insulated Gate Bipolar Transistor), a bipolar transistor, or an electric field transistor. Since there is a switching element which has a collector terminal connected to the DC-power-transmission network-A side and which has a collector terminal connected to the DC-power-transmission network-B side, the current in both directions from the DC power transmission network A to B or from B to A can be flown or broken.

[0018] The semiconductor circuit breaker 4 changes the state between the ON state which is a conduction state, and the OFF state which is a current breaking state based on an input gate signal. In the conduction state, the current is supplied to the parallel circuit 3 from the DC power transmission system via the semiconductor circuit breaker 4, and in the current breaking state, the current to the parallel circuit 3 from the DC power transmission system is broken.

[0019] The arrester 43 including a non-linear element that flows a current when voltage of equal to or greater than a certain voltage is applied is connected in parallel with the semiconductor circuit breaker 4. When the semiconductor circuit breaker 4 is changed to the OFF state, the arrester 43 absorbs a surge voltage, enabling a safe current breaking.

[0020] The H bridge circuit 5 includes a plurality of H-bridge units 50 connected in series. Each H-bridge unit 50 has two legs 52 having two switching elements 51 connected in series. Each switching element 51 applied has a self-arc-extinguishing ability. A diode is connected in parallel with each switching element 51. These two legs 52 are connected in parallel, and a capacitor 53 is further connected in parallel with the two legs 52. The capacitor 53 is charged by the current flowing through the power transmission line 100 at the time of a normal operation.

[0021] As described later in detail, the reactor 55 is for reducing a current change rate, and is provided so as to enable the H-bridge circuit 5 to control the current.

(Operation)

[0022] The operation of the DC breaker 1 employing the above structure will be described with reference to FIGs. 2 to 6 separately in a case of the normal time and a case in which a fault occurs. In the normal times, the mechanical disconnection switch 2 and the mechanical circuit breaker 20 are controlled to be in the ON state, while the semiconductor circuit breaker 4 and the H bridge circuit 5 are controlled to be in the OFF state. As

illustrated in FIG. 2, the current from the DC power transmission network A passes only through the mechanical disconnection switch 2 and the mechanical circuit breaker 20, and flows into the DC power transmission network B, and does not flow into the parallel circuit 3 and the H bridge circuit 5.

[0023] To describe the operation of the DC breaker 1 when a fault occurs, FIG. 3 is referred. FIG. 3 is a diagram illustrating the operating state of a simulation execution circuit executed in order to describe the validity of the above DC breaker 1. The simulation execution circuit was connected to the DC breaker 1 illustrated in FIG. 1 in the circuit structure simulating the current transmission network A, and after a DC voltage of 320 kV was applied to this DC breaker 1, a ground fault originating from lightning strike, etc., was caused in the power transmission line 100 of the simulated current transmission network A. (i) indicated by a thick solid line in FIG. 3 indicates the current flowing through the mechanical circuit breaker 20. (ii) indicated by a dashed-dotted line indicates the current flowing through the H bridge circuit 5. (iii) indicated by a dashed-two dotted line indicates the current flowing through the semiconductor circuit breaker 4.

[0024] A fault current increases along with time when the fault occurs. The DC breaker 1 performs the breaking operations in two stages as a whole. First, at the initial stage in which the fault current is small, the DC breaker performs the breaking operation of the mechanical circuit breaker 20 to commute the fault current to the parallel circuit 3, and at the latter stage in which the fault current is increased, performs the breaking operation of the semiconductor circuit breaker 4. The details will be described below.

[0025] When a grounding fault occurs at a time t_1 , the current flowing through the mechanical circuit breaker 20 increases as indicated by (i). The current sensor attached to the mechanical circuit breaker 20 detects a current I_{dc_M} flowing through the mechanical circuit breaker 20, and compares the detected current with the preset fault occurrence detection threshold I_{dc_J} . At a time t_2 at which the detected current I_{dc_M} exceeds the threshold I_{dc_J} , the gate signal to the switching element 41 in the semiconductor circuit breaker 4 of the parallel circuit 3 is changed from the OFF to the ON. Simultaneously, an output voltage control is performed on the H-bridge circuit 5. More specifically, an output voltage V_H of the H-bridge circuit 5 is calculated by the following formula, and is output.

$$V_H = G(s) \times (I_{dcM} - 0)$$

(where $G(s)$ is a control gain, and s is a Laplace operator)

[0026] $G(s)$ is a control gain, and for example, performs a general proportional integration control.

[0027] That is, by performing a pulse width modulation control according to the ON and OFF ratio (duty) that

defines beforehand the switching element 51 in each leg 52 of the each of the H-bridge units 50, the current I_{dc_M} flowing through the mechanical circuit breaker 20 is continuously controlled to be substantially zero. In other words, the output voltage V_H of the H-bridge unit 50 is output variably by performing the pulse width modulation control on the switching element 51 in each of the leg 52.

[0028] By the control by the H-bridge circuit 5, as indicated by (i) in FIG. 3, The current I_{dc_M} flowing through the mechanical circuit breaker 20 is continuously controlled to be substantially zero. In this condition, the mechanical circuit breaker 20 is transitioned to the OFF state. Since the current flowing through the mechanical circuit breaker 20 is substantially zero, even when the contacts are transitioned to the OFF state, unlike the normal DC conduction, an arc is not drawn and the current does not keep flowing. Hence, the current can be broken at fast speed.

[0029] When the output voltage control using the H-bridge unit 50 is performed, the output voltage of the H-bridge unit 50 is directly applied to the mechanical circuit breaker 20 which has a conduction resistance of substantially zero, a short-circuit current may flow, and the current control may be disabled. According to this embodiment, however, the reactor 55 for reducing the current change rate is provided in the parallel circuit 3 connected to the H-bridge circuit 5. This reactor 55 prevents the output voltage of the H-bridge unit 50 from being directly applied to the mechanical circuit breaker 20, enabling a control on the current flowing through the mechanical circuit breaker 20.

[0030] More specifically, a change rate dI_{dc_M}/dt of the current I_{dc_M} flowing through the mechanical circuit breaker 20 is expressed as the following formula using an inductance value L of the reactor 55.

$$dI_{dc_M}/dt = V_H/L$$

[0031] When there is no reactor 55, the inductance value is $L = 0$, and if the output voltage V_H of the H-bridge unit 50 is not zero, the current change rate dI_{dc_M}/dt becomes infinite, and the current I_{dc_M} flowing through the mechanical circuit breaker 20 could not be controlled. According to this embodiment, since the inductance value L is inserted in the above formula by providing the reactor 55 in the parallel circuit 3, the current change rate dI_{dc_M}/dt becomes finite. This enables a control on the current change rate dI_{dc_M}/dt in accordance with the magnitude of the output voltage V_H of the H-bridge unit 50. Accordingly, the output voltage of the H-bridge unit 50 is prevented from being directly applied to the mechanical circuit breaker 20, enabling a current control to make the flowing current I_{dc_M} through the mechanical circuit breaker 20 substantially zero.

[0032] By the output voltage control using the H-bridge circuit 5, the current I_{dc_M} flowing through the mechan-

ical circuit breaker 20 is continuously controlled until becoming substantially zero. More specifically, as illustrated in FIG. 4, the current flowing through the power transmission line 100 passes through the H-bridge circuit 5 without passing through the mechanical circuit breaker 20, and further passes through the parallel circuit 3 connected to the H-bridge circuit 5, and returns to the power transmission line 100. Hence, the current I_{dc_M} flowing through the mechanical circuit breaker 20 becomes substantially zero. In this condition, the mechanical circuit breaker 20 is transitioned to the OFF state. Since the current flowing through the mechanical circuit breaker 20 is substantially zero, even when the contact is transitioned to the OFF state, unlike the normal DC conduction, an arc is not drawn and the current does not keep flowing. Hence, the current can be interrupted at fast speed.

[0033] Next, as illustrated in FIG. 5, all switching elements 51 of the H-bridge units 50 are turned OFF (see (ii) in FIG. 3). In this case, the voltage stored beforehand in the capacitors 53 of the H-bridge units 50 are applied in the direction decreasing the fault current continuously flowing through the mechanical disconnection switch 2. This causes the fault current flowing through the mechanical disconnection switch 2 to decrease. The fault current is commutated to the parallel circuit 3 connected in parallel with the mechanical disconnection switch 2 in an amount of the decreased fault current flowing through the mechanical disconnection switch 2. As indicated by (iii) in FIG. 3, the current flowing through the semiconductor circuit breaker 4 increases, and as time advances, the current flowing through the mechanical disconnection switch 2 eventually becomes zero, and all fault current flows through the semiconductor circuit breaker 4. The mechanical disconnection switch 2 is turned OFF at this timing. Since no current flows through the mechanical disconnection switch 2, at the time of disconnection of contacts, no arc is produced and the current does not keep flowing.

[0034] Finally, as illustrated in FIG. 6, the gate signal to the switching element 41 of the semiconductor circuit breaker 4 is changed to OFF from ON, to break the fault current which flows through the parallel circuit 3. The surge voltage produced at this time is absorbed by the arrester 43, and the current breaking is completed.

(Effect)

[0035] As described above, according to the first embodiment, the DC breaker 1 includes the mechanical disconnection switch 2 provided at the power transmission line 100, the mechanical circuit breaker 20 connected in series to the mechanical disconnection switch 2, and the parallel circuit 3 connected in parallel with the mechanical disconnection switch 2 and the mechanical circuit breaker 20. The parallel circuit 3 includes the semiconductor circuit breaker 4 that changes a supply and breaking of the current from the power transmission line 100 to the parallel circuit 3, and the reactor 55 connected in series

to the semiconductor circuit breaker 4. The DC breaker 1 is further provided with the H-bridge circuit 5 which connects one point between the mechanical disconnection switch 2 and the mechanical circuit breaker 20 to one point between the semiconductor circuit breaker 4 and the reactor 55. The H-bridge circuit 5 includes the H-bridge units 50 each including the plurality of the switching elements 51 and the capacitor 53. The H-bridge circuit 5 controls the current flowing through the mechanical circuit breaker 20 by the output voltage control.

[0036] In the normal times, since the current passes only through the mechanical disconnection switch 2 and the mechanical circuit breaker 20, the conduction loss can be reduced, and thus the efficient DC breaker 1 can be provided. At the time of a fault, by the output voltage control using the H-bridge circuits 5, the current is guided to the parallel circuit 3 and the current flowing through the mechanical disconnection switch 2 is set to be the amount enabling a disconnection of the circuit without producing an arc, that is, substantially zero to perform the disconnection of the fault point safely even if the mechanical disconnection switch 2 having no current breaking capability. In addition, fast-speed current breaking is enabled by the semiconductor circuit breaker 4 provided in the parallel circuit 3. According to such effect, the DC breaker according to this embodiment contributes to the improvement of the power transmission efficiency, the cost reduction, and the improvement of the reliability in DC power transmission.

[0037] Still further, the H-bridge circuit 5 is provided to connect one point between the mechanical disconnection switch 2 and the mechanical circuit breaker 20 to one point between the semiconductor circuit breaker 4 and the reactor 55. Hence, the current flows through the H-bridge circuit 5 only in the initial stage at which the fault current is small when breaking the mechanical circuit breaker 20 is small. That is, the maximum value of the current flowing through the H-bridge circuit 5 is the fault current at a time the mechanical circuit breaker 20 is turned OFF. Subsequently, the fault current which increases when the time has elapsed until the mechanical disconnection switch 2 is turned OFF flows in and through the parallel circuit 3, and the maximum current capacity of the semiconductor switching element 51 configuring the H-bridge circuit 5 can be reduced to a capacity that is remarkably smaller than the maximum current capacity of the switching element 41 configuring the semiconductor circuit breaker 4. In addition, since the reactor 55 is provided in the parallel circuit 3, the output voltage of the H-bridge circuit 5 is not directly applied to the mechanical circuit breaker 20, enabling a precise current control.

[0038] Still further, the H-bridge circuit 5 includes the plurality of the H-bridge units 50 connected in series. Since the charging and discharging amount can be increased by increasing the number of the capacitors 53 provided in the respective H-bridge units 50, it becomes possible for the DC breaker to cope with a large fault

current.

(Second Embodiment)

[0039] A second embodiment will be described with reference to FIG. 7. In the second embodiment, only the differences from the first embodiment will be described, the same component as that of the first embodiment will be denoted by the same reference numeral, and the detailed explanation thereof will not be repeated.

(Structure)

[0040] In this embodiment, the DC breaker 1 does not include the H-bridge circuit 5. The parallel circuit 3 connected in parallel with the mechanical disconnection switch 2 and the mechanical circuit breaker 20 includes two semiconductor circuit breakers 4A, 4B connected in series.

[0041] The semiconductor circuit breaker 4A includes two or more switching elements 41a having a self-extinguishing ability and connected in series, and a diode 42a is connected in reverse parallel with each of the switching element 41a. In the example illustrated in FIG. 7, an example structure in which three switching elements are connected is illustrated. The semiconductor circuit breaker 4A has a collector terminal connected to the DC-power-transmission-network-A side.

[0042] The semiconductor circuit breaker 4B includes two or more switching elements 41b having a self-extinguishing ability and connected in series, and a diode 42b is connected in reverse parallel with each of the switching element 41b. In the example illustrated in FIG. 7, an example structure in which three switching elements are connected is illustrated. The semiconductor circuit breaker 4B has a collector terminal connected to the DC-power-transmission-network-B side. That is, the switching element 41b of the semiconductor circuit breaker 4B has the collector and the emitter in the opposite direction to those of the switching element 41a of the semiconductor circuit breaker 4A.

[0043] The semiconductor circuit breakers 4A, 4B have respective emitters connected to each other via the reactor 55. The reactor 55 is provided to reduce the current change rate of the parallel circuit 3, but the reactor 55 may be omitted by utilizing a wiring inductance. In addition, in the example in FIG. 7, the reactor 55 is provided between the semiconductor circuit breakers 4A, 4B, but the location where the reactor is provided is not limited to this case. In the parallel circuit 3, there is no difference in function even when the reactor is provided next to the DC-power-transmission-network-A side of the semiconductor circuit breaker 4A or next to the DC-power-transmission-network-B side of the semiconductor circuit breaker 4B.

[0044] A reverse current generation circuit 6A is connected in reverse parallel with one of the switching elements 41a configuring the semiconductor circuit breaker

4A. The reverse current generation circuit 6A includes a switching element 61a, a diode 62a connected in reverse parallel with the switching element 61a, and a capacitor 63a connected in series to the switching element 61a. The collector side of the switching element 41a of the reverse current generation circuit 6A is connected to the emitter side of the switching element 61a of the reverse current generation circuit 6A. The collector side of the reverse current generation circuit 6A is connected to the positive-side terminal of the capacitor 63a. The negative-side terminal of the capacitor 63a is connected to the emitter side of the switching element 41a of the semiconductor circuit breaker 4A.

[0045] A reverse current generation circuit 6B is connected in reverse parallel with one of the switching elements 41b configuring the semiconductor circuit breaker 4B. The reverse current generation circuit 6B includes a switching element 61b, a diode 62b connected in reverse parallel with the switching element 61b, and a capacitor 63b connected in series to the switching element 61b. The collector side of the switching element 41b of the semiconductor circuit breaker 4B is connected to the emitter side of the switching element 61b of the reverse current generation circuit 6B. The collector side of the reverse current generation circuit 6B is connected to the positive-side terminal of the capacitor 63b. The negative-side terminal of the capacitor 63b is connected to the emitter side of the switching element 41a of the semiconductor circuit breaker 4A. That is, the switching 61b of the reverse current generation circuit 6B is provided to conduct the current in the opposite direction to that of the switching element 61a of the reverse current generation circuit 6A.

[0046] The switching elements 61a, 61b configuring the reverse current generation circuits 6A, 6B may have a capacity smaller than the maximum current capacity of the switching elements 41a, 41b configuring the semiconductor circuit breakers 4A and 4B.

[0047] Although the reverse current generation circuits 6A, 6B are respectively connected in reverse parallel with one of the switching elements 41a, 41b configuring the semiconductor circuit breakers 4A, 4B, those may be connected in reverse parallel with the plurality of the switching elements 41a, 41b. Since the semiconductor circuit breakers 4A, 4B each have three switching elements 41a, 41b in the example illustrated in FIG. 7, the reverse current generation circuits 6A, 6B may be connected in reverse parallel with the two or the three switching elements 41a, 41b, respectively.

(Operation)

[0048] The operation of the DC breaker 1 employing the above structure will be explained separately in the case of the normal times and in the case in which a fault occurs. As for the case in which a fault occurs, a case in which a DC short-circuit fault is occurred at the DC-power-transmission-network-B side will be described. In the

normal times, the mechanical disconnection switch 2 and the mechanical circuit breaker 20 are controlled to be in the ON state, and the semiconductor circuit breakers 4A, 4B, and the reverse current generation circuits 6A, 6B are controlled to be in the OFF state. The current from the DC power transmission network A passes only through the mechanical disconnection switch 2 and the mechanical circuit breaker 20, and flows into the DC power transmission network B, but does not flow into the parallel circuit 3.

[0049] When the current sensor attached to the mechanical circuit breaker 20 detects a current I_{dc_M} exceeding a threshold I_{dc_J} when the fault occurs, the switching element 41a of the semiconductor circuit breaker 4A having the collector connected to the DC power-transmission-network-A side is transitioned to the ON state, and the switching element 61b of the reverse current generation circuit 6B connected in reverse parallel with the semiconductor circuit breaker 4B is transitioned to the ON state.

[0050] By the capacitor voltage charged beforehand in the capacitor 63b of the reverse current generation circuit 6B, a circulation circuit passing the diode 42b of the semiconductor circuit breaker 4B having the collector connected to the DC-power-transmission-network-B side, the mechanical disconnection switch 2, the mechanical circuit breaker 20, the switching element 41a of the semiconductor circuit breaker 4A having the collector connected to the DC-power-transmission-network-A side, and the reactor 55. This circulation circuit superimposes the fault current flowing through the mechanical circuit breaker 20 when the fault occurs to the current in the opposite direction. Hence, the current I_{dc_M} which flows through the mechanical circuit breaker 20 is controlled to be substantially zero. In this condition, the mechanical circuit breaker 20 is transitioned to the OFF state. Since the current flowing through the mechanical circuit breaker 20 is substantially zero, even when the contacts are transitioned to the OFF state, an arc is not drawn and the current keeps flowing unlike the normal times. Accordingly, the current can be broken at fast speed.

[0051] Next, the switching element 61b of the reverse current generation circuit 6B is turned OFF. In addition, the mechanical disconnection switch 2 is turned OFF. The fault current which increases as time advances flows only through the parallel circuit 3. In this case, by changing the gate signal for the switching element 41a of the semiconductor circuit breaker 4A from ON to OFF, eventually, the fault current is broken.

[0052] When a fault occurs in the DC-power-transmission-network-A side, a left-right reverse operation to the case in which the fault occurs at the DC-power-transmission-network-B side is performed. That is, the switching element 41b of the semiconductor circuit breaker 4B having the collector connected to the DC-power-transmission-network-B side is transitioned to the ON state, and the switching element 61a of the reverse current generation circuit 6A is turned ON. By the capacitor voltage

charged beforehand in the capacitor 63a of the reverse current generation circuit 6A, a circulation circuit is formed which passes through the diode 42a of the semiconductor circuit breaker 4A having the collector connected to the DC-power-transmission-network-A side, the mechanical disconnection switch 2, the mechanical circuit breaker 20, the switching element 41b of the semiconductor circuit breaker 4B having the collector connected to the DC-power-transmission-network-B side, and the reactor 55. This circulation circuit superimposes the fault current flowing through the mechanical circuit breaker 20 when the fault occurs to the current in the opposite direction. The current I_{dc_M} flowing through the mechanical circuit breaker 20 is controlled to be substantially zero, and in this condition, the mechanical circuit breaker 20 is transitioned to the OFF state.

(1) As described above, according to the second embodiment, the parallel circuit 3 includes a set of two semiconductor circuit breakers 4A, 4B instead of the structure in which the DC breaker 1 includes the H-bridge circuit 5, and the reverse current generation circuits 6A, 6B connected in reverse parallel with the semiconductor circuit breakers 4A, 4B, respectively, are further provided. The semiconductor circuit breakers 4A, 4B each include the plurality of the switching elements 41a connected in series, and are provided so as to conduct the current supplied from the power transmission line 100 in the opposite directions to each other. The reverse current generation circuits 6A, 6B are connected in reverse parallel with one or more switching elements 41a, 41b configuring the semiconductor circuit breaker 4A, 4B, and superimposes the fault current flowing through the mechanical circuit breaker 20 when the fault occurs to the current in the opposite direction.

By employing such structure, like the first embodiment, the current passes only through the mechanical disconnection switch 2 and the mechanical circuit breaker 20 in the normal times, and the conduction loss can be reduced and the efficient DC breaker 1 can be provided. Since the reverse current generation circuits 6A, 6B superimpose the current flowing through the mechanical circuit breaker 20 to the current in the opposite direction when the fault occurs, the current flowing through the mechanical circuit breaker 20 can be made substantially zero, and the fault point can be safely disconnected. In addition, the semiconductor circuit breaker 4 provided in the parallel circuit 3 enables a fast-speed current breaking. Such effects contribute to the improvement of the power transmission efficiency, the cost reduction, and the improvement of the reliability in DC power transmission.

Still further, since the reverse current generation circuits 6A, 6B are connected in reverse parallel with the semiconductor circuit breakers 4A, 4B, the current flows through the reverse current generation cir-

cuits 6A, 6B only in an initial stage at which the fault current is small when breaking the mechanical circuit breaker 20. That is, the maximum value of the current flowing through the reverse current generation circuits 6A, 6B is the fault current until in the mechanical circuit breaker 20 is turned OFF. The fault current increased as time advances after the mechanical circuit breaker 20 is turned OFF flows through the semiconductor circuit breakers 4A, 4B connected in reverse parallel with the reverse current generation circuits 6A, 6B. Hence, the maximum current capacity of the switching elements 61a, 61b configuring the reverse current generation circuits 6A, 6B can be smaller than the maximum current capacity of the switching elements 41a, 41b configuring the semiconductor circuit breakers 4A, 4B, enabling a cost reduction of the DC breaker 1.

(2) The parallel circuit 3 includes the reactor 55 connected in series to the semiconductor circuit breaker 4A and the semiconductor circuit breaker 4B. The reactor 55 performs smoothing on the current flowing through the parallel circuit 3, and reduces a current change rate, enabling a precise output voltage control.

(Other Embodiments)

[0053] The present disclosure is not limited directly to the above embodiments, and structural components can be modified without departing from the scope of the present disclosure when implemented. Various species of the present disclosure can be made by an appropriate combination of the plurality of the structural components disclosed in the above embodiments. For example, several structural components among all structural components may be omitted. In addition, structural components from different embodiments may be combined to carry out the present disclosure.

REFERENCE SIGNS LIST

[0054]

- 1 DC breaker
- 2 Mechanical disconnection switch
- 20 Mechanical circuit breaker
- 3 Parallel circuit
- 4, 4A, 4B Semiconductor circuit breaker
- 41, 41a, 41b Switching element
- 42, 42a, 42b Diode
- 43 Arrester
- 5 H-bridge circuit
- 50 H-bridge unit
- 51 Switching element
- 52 Leg
- 53 Capacitor
- 55 Reactor
- 6A, 6B Reverse current generation circuit

61a, 61b Switching element
 62a, 62b Diode
 63a, 63b Capacitor
 100 Positive-side power transmission line
 101 Negative-side power transmission line
 A, B DC power transmission network

Claims

1. A DC breaker comprising:

a mechanical disconnection switch provided in a DC power transmission system;
 a mechanical circuit breaker provided in the DC power transmission system, and connected in series to the mechanical disconnection switch;
 a parallel circuit which is connected in parallel with the mechanical disconnection switch and the mechanical circuit breaker, and which comprises a semiconductor circuit breaker that changes a supply or a breaking of a current of the DC power transmission system, and a reactor connected in series to the semiconductor circuit breaker; and
 an H-bridge circuit that controls a current flowing through the mechanical circuit breaker by an output voltage control, and comprises an H-bridge unit which connects one point between the mechanical disconnection switch and the mechanical circuit breaker to one point between the semiconductor circuit breaker and the reactor, and which comprises a plurality of switching elements and a capacitor.

2. The DC breaker according to claim 1, wherein when a fault occurs in the DC power transmission system:

the semiconductor circuit breaker and the H-bridge unit are transitioned to an ON state, the current flowing through the mechanical circuit breaker is controlled to be substantially zero by an output voltage control on the H-bridge circuit, and the mechanical circuit breaker is transitioned to an OFF state; and
 the H-bridge unit is transitioned to an OFF state, a fault current is commutated to the parallel circuit by a voltage application from the capacitor of the H-bridge circuit, the mechanical disconnection switch is transitioned to an OFF state, and the fault current is broken by the semiconductor circuit breaker.

3. The DC breaker according to claim 1 or 2, wherein the H-bridge circuit comprises a plurality of the H-bridge units connected in series.

4. A DC breaker comprising:

a mechanical disconnection switch provided in a DC power transmission system;
 a mechanical circuit breaker provided in the DC power transmission system, and connected in series to the mechanical disconnection switch;
 a parallel circuit which is connected in parallel with the mechanical disconnection switch and the mechanical circuit breaker, and which comprises a first semiconductor circuit breaker comprising a plurality of switching elements connected in series and conducting a current supplied from the DC power transmission system in a first direction, and a second semiconductor circuit breaker comprising a plurality of switching elements connected in series and conducting a current supplied from the DC power transmission system in a second direction opposite to the first direction;
 a first reverse current generation circuit connected in reverse parallel with one of or the plurality of switching elements configuring the first semiconductor circuit breaker, comprising a switching element and a capacitor, and superimposing a current flowing through the mechanical circuit breaker to a current in an opposite direction; and
 a second reverse current generation circuit connected in reverse parallel with one of or the plurality of switching elements configuring the second semiconductor circuit breaker, comprising a switching element and a capacitor, and superimposing the current flowing through the mechanical circuit breaker to a current in an opposite direction.

5. The DC breaker according to claim 4, wherein when a fault occurs in the DC power transmission system:

the first semiconductor circuit breaker and the second reverse current generation circuit are transitioned to an ON state, the current flowing through the mechanical circuit breaker is superimposed to a current in the opposite direction by a capacitor voltage of the second reverse current generation circuit to control the current flowing through the mechanical circuit breaker to be substantially zero, the mechanical circuit breaker is transitioned to an OFF state, the second reverse current generation circuit is transitioned to an OFF state, the mechanical disconnection switch is transitioned to an OFF state, and the semiconductor circuit breaker breaks the fault current.

6. The DC breaker according to claim 4, wherein when a fault occurs in the DC power transmission system:

the second semiconductor circuit breaker and the first reverse current generation circuit are

transitioned to an ON state, the current flowing through the mechanical circuit breaker is superimposed to a current in the opposite direction by a capacitor voltage of the first reverse current generation circuit to control the current flowing through the mechanical circuit breaker to be substantially zero, the mechanical circuit breaker is transitioned to an OFF state, the first reverse current generation circuit is transitioned to an OFF state, the mechanical disconnection switch is transitioned to an OFF state, and the semiconductor circuit breaker breaks the fault current.

7. The DC breaker according to any one of claims 4 to 6, wherein the parallel circuit comprises a reactor connected in series to the first semiconductor circuit breaker and the second semiconductor circuit breaker.

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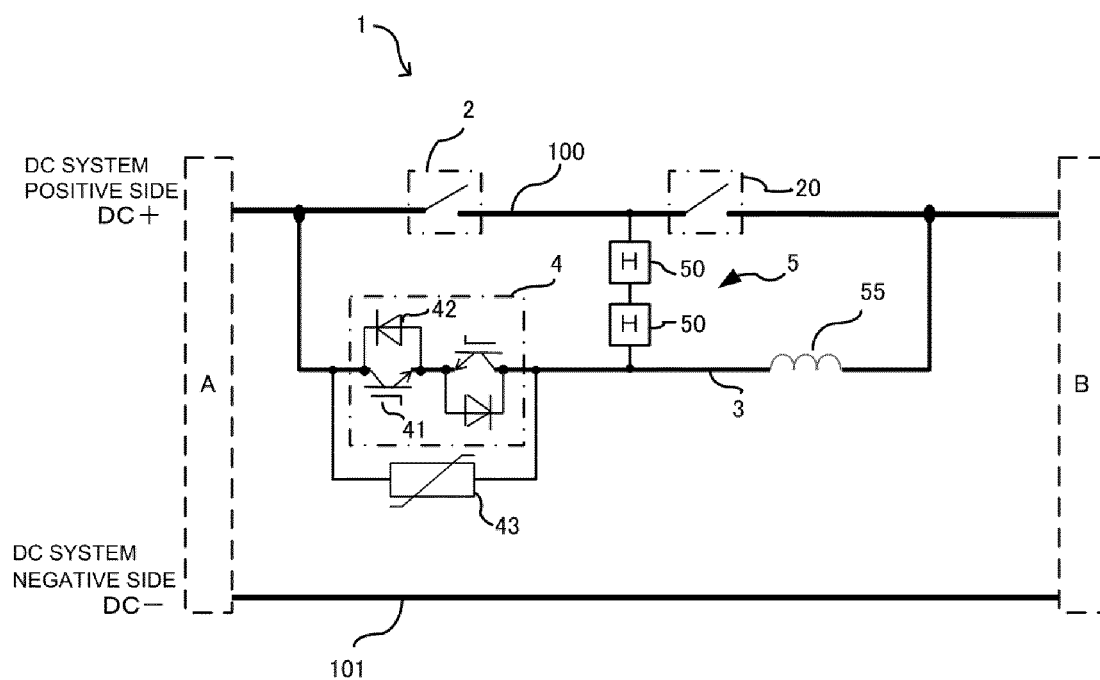


FIG. 1 (a)

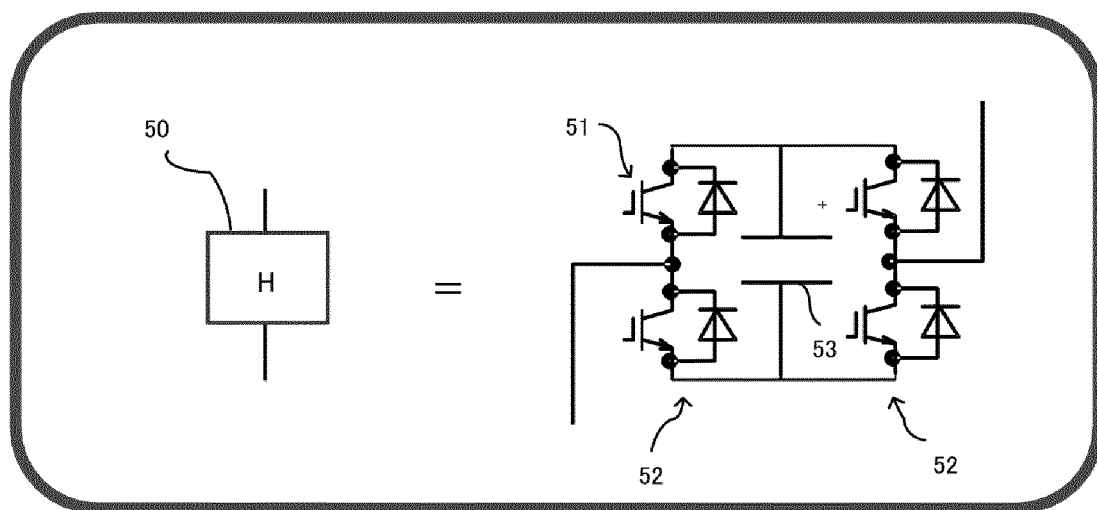


FIG. 1 (b)

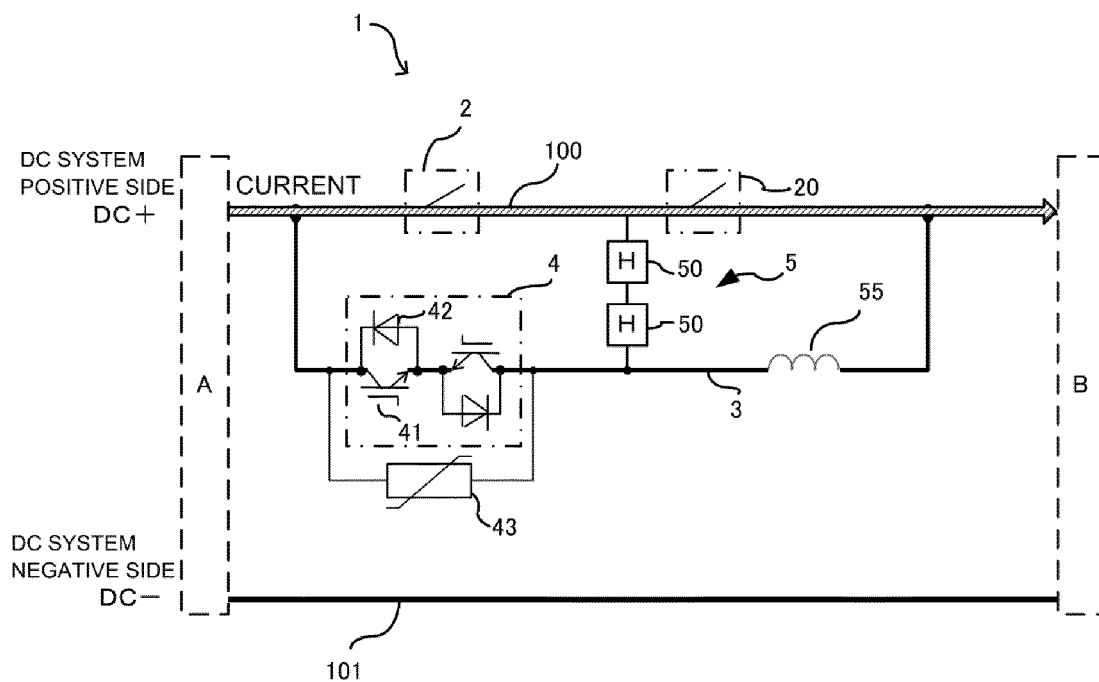


FIG. 2

P1=H-BRIDGE UNIT OUTPUT VOLTAGE CONTROL
P2=H-BRIDGE UNIT OFF

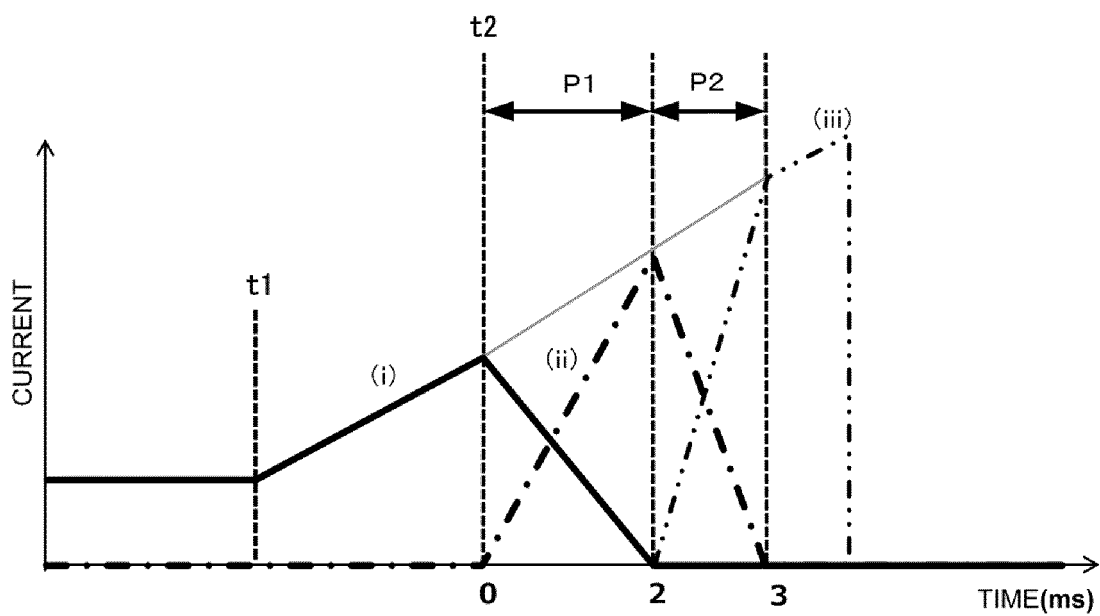


FIG. 3

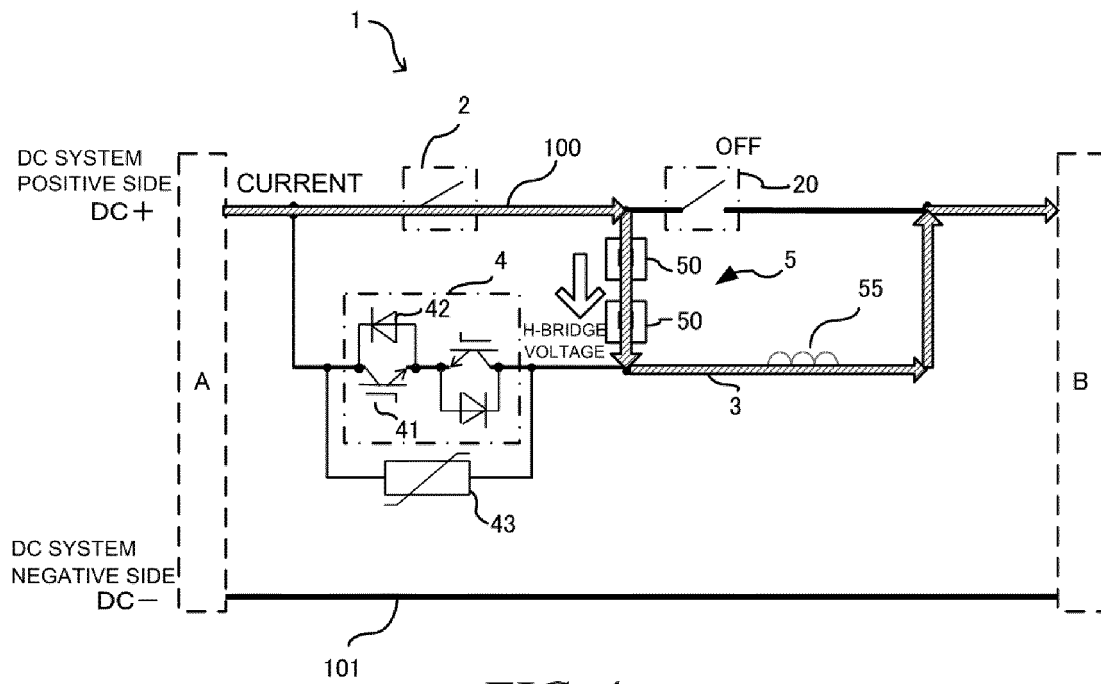


FIG. 4

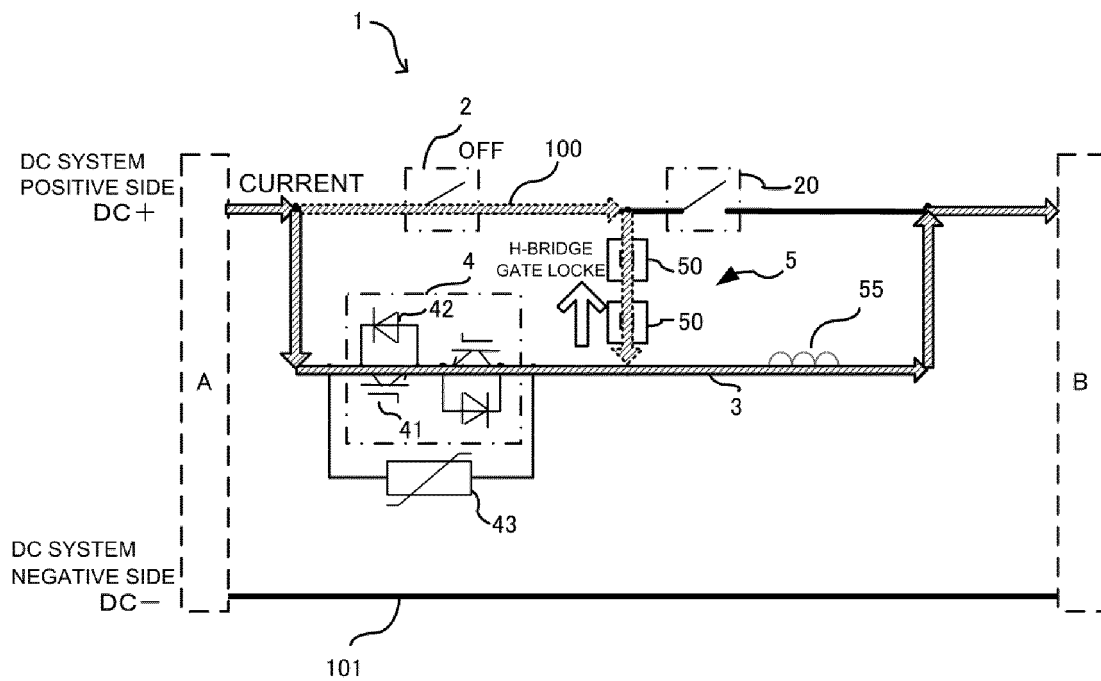


FIG. 5

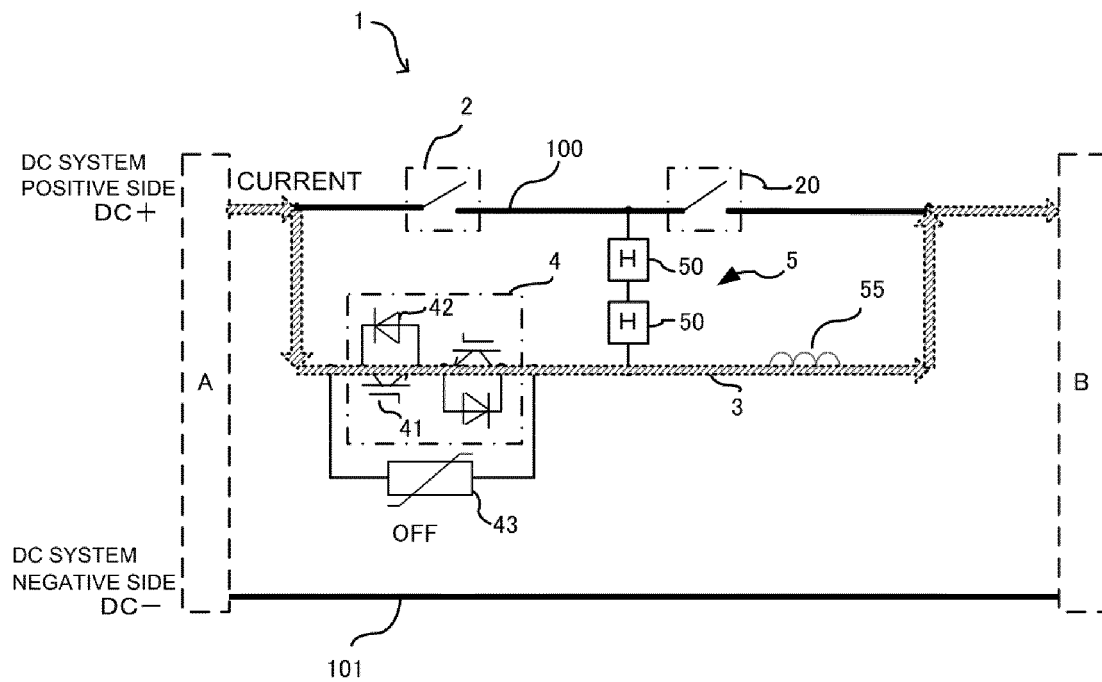


FIG. 6

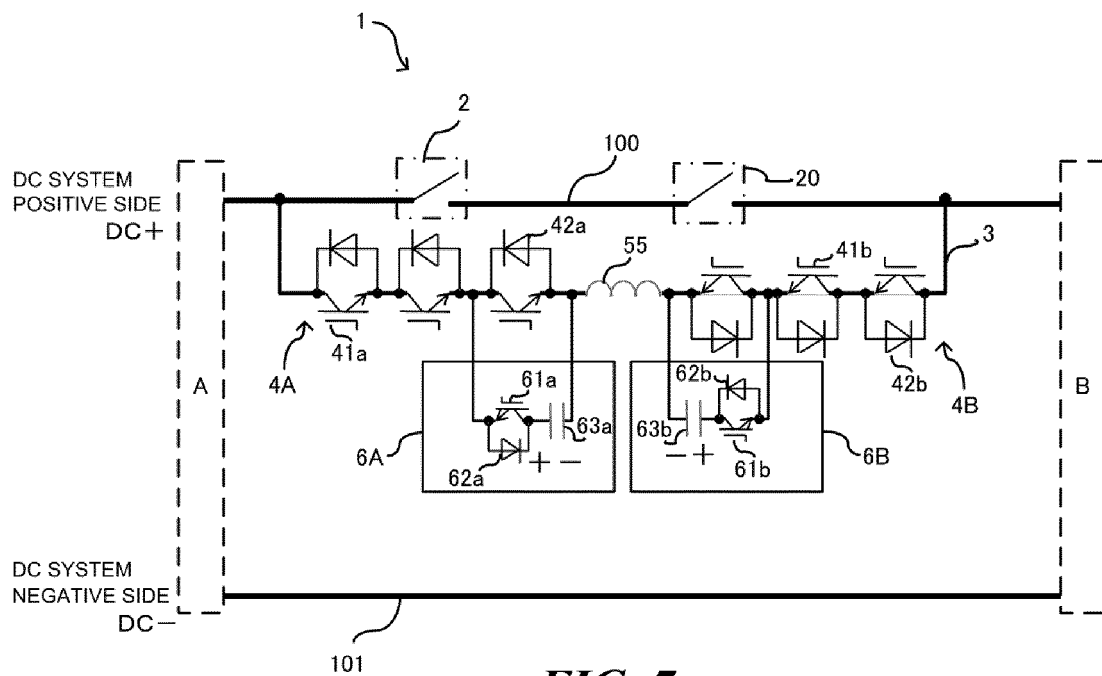


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/055395

A. CLASSIFICATION OF SUBJECT MATTER

H01H33/59(2006.01)i, H01H9/54(2006.01)i

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)

H01H33/59, H01H9/54

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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.
Y	JP 10-126961 A (Fuji Electric Co., Ltd.),	4-7
A	15 May 1998 (15.05.1998), paragraph [0028]; fig. 5 (Family: none)	1-3
Y	JP 55-126923 A (Tokyo Shibaura Electric Co., Ltd.), 01 October 1980 (01.10.1980), page 2, upper left column, line 17 to lower left column, line 4; page 2, lower left column, lines 12 to 15; fig. 2 (Family: none)	4-7

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

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"&" document member of the same patent family

Date of the actual completion of the international search
10 May 2016 (10.05.16)Date of mailing of the international search report
24 May 2016 (24.05.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/055395

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 54-132776 A (Electric Power Development Co., Ltd.), 16 October 1979 (16.10.1979), page 5, lower right column, line 19 to page 6, upper right column, line 12; fig. 9 to 10 (Family: none)	4-7
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 99869/1985 (Laid-open No. 7738/1987) (Meidensha Corp.), 17 January 1987 (17.01.1987), specification, page 7, line 8 to page 12, line 1; fig. 1 to 2 (Family: none)	4-7
A	JP 2014-175077 A (Mitsubishi Electric Corp.), 22 September 2014 (22.09.2014), entire text; all drawings (Family: none)	1-7
A	JP 2014-235834 A (Toshiba Corp.), 15 December 2014 (15.12.2014), entire text; all drawings (Family: none)	1-7
A	WO 2014/094847 A1 (SIEMENS AG), 26 June 2014 (26.06.2014), entire text; all drawings & US 2015/0333496 A1 & EP 2907152 A1 & CN 104838462 A	1-7

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REFERENCES CITED IN THE DESCRIPTION

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