(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 352 193 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
25.07.2018 Bulletin 2018/30

(21) Application number: **15904074.0**

(22) Date of filing: **16.09.2015**

(51) Int Cl.:
H01H 33/59 *(2006.01)* ***H01H 73/18*** *(2006.01)*

(86) International application number:
PCT/JP2015/076243

(87) International publication number:
WO 2017/046885 (23.03.2017 Gazette 2017/12)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

(71) Applicant: **Mitsubishi Electric Corporation**
Chiyoda-ku
Tokyo 100-8310 (JP)

(72) Inventor: **MIYOSHI, Nobuo**
Tokyo 100-8310 (JP)

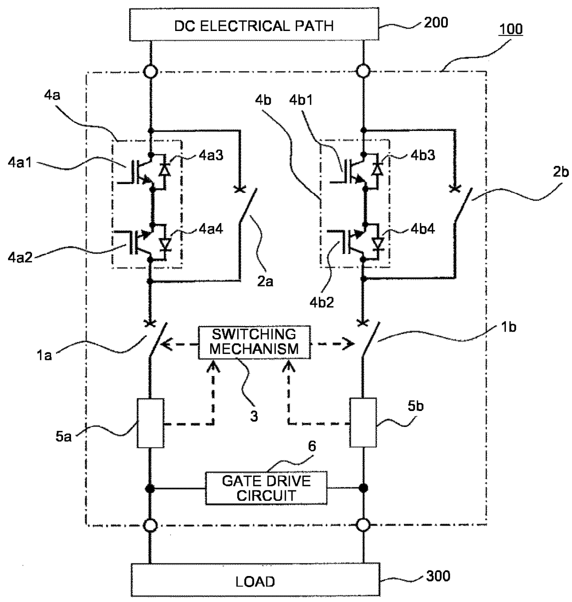
(74) Representative: **Diehl & Partner GbR**
Patentanwälte
Erika-Mann-Strasse 9
80636 München (DE)

(54) **CIRCUIT BREAKER**

(57) According to the present invention, a direct-current circuit breaker for a high voltage is obtained, which can reliably interrupt current ranging from a low current that is lower than or equal to 1 kA to a ground-fault current exceeding 1 kA.

A circuit breaker includes: a first switching contact (1a, 1b) that opens and closes a direct-current electrical path (200); a second switching contact (2a, 2b) that is connected in series with the first switching contact (1a, 1b) and opens and closes the direct-current electrical path (200); and a semiconductor switch (4a, 4b) that is connected to both ends of the second switching contact (2a, 2b) such that the semiconductor switch (4a, 4b) is in parallel with the second switching contact (2a, 2b) and that opens and closes the direct-current electrical path (200). When a closing operation is performed, the semiconductor switch (4a, 4b) is closed after the first switching contact (1a, 1b) and the second switching contact (2a, 2b) are closed, and when an interrupting operation is performed, the semiconductor switch (4a, 4b) is opened after the first switching contact (1a, 1b) and the second switching contact (2a, 2b) are opened.

FIG.1



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Description

Field

[0001] The present invention relates to a circuit breaker that interrupts a high-voltage direct-current circuit.

Background

[0002] A typical method to achieve a higher-voltage circuit breaker used for a direct-current circuit is to increase the arc voltage, generated when the switching contacts of the circuit breaker are separated, by increasing the opening distance between the switching contacts in accordance with the circuit voltage. However, increasing the opening distance between the switching contacts increases the size of a circuit breaker and this runs counter to the current need for downsizing.

[0003] To counter this, a technology has been proposed as a method for interrupting a direct-current circuit without increasing the opening distance between switching contacts. In this technology, a semiconductor switch is connected between the switching contacts such that the semiconductor switch is in parallel with the switching contacts, and, during an opening and closing operation of the switching contacts, current is diverted to the semiconductor switch so that the arc generated between the switching contacts is immediately extinguished and thereafter the semiconductor switch is turned off to interrupt the current (for example, see Patent Literatures 1 and 2).

Citation List

Patent Literature

[0004]

Patent Literature 1: Japanese Patent Application Laid-open No. 2012-248445
Patent Literature 2: Japanese Patent Application Laid-open No. 2014-38775

Summary

Technical Problem

[0005] With the conventional circuit breaker configured as above, in a case where a semiconductor switch is selected in accordance with the rated current, interrupting a high interrupting current, e.g., current exceeding 1 kA, may cause the semiconductor switch to break. Moreover, in a case where a semiconductor switch is selected for a high current, a problem arises in that the size of the semiconductor switch increases relative to the circuit breaker.

[0006] An object of the present invention is to provide a direct-current circuit breaker for a high voltage that can reliably interrupt current ranging from a low current that is lower than or equal to 100 A to a fault current exceeding 1 kA.

Solution to Problem

[0007] A circuit breaker according to an aspect of the present invention includes: a first switching contact that opens and closes an electrical path; a second switching contact that is connected in series with the first switching contact and opens and closes the electrical path; and a semiconductor switch that is connected to both ends of the second switching contact such that the semiconductor switch is in parallel with the second switching contact and that opens and closes the electrical path. When a closing operation is performed, the semiconductor switch is closed after the first switching contact and the second switching contact are closed, and when an interrupting operation is performed, the semiconductor switch is opened after the first switching contact and the second switching contact are opened.

Advantageous Effects of Invention

[0008] According to the present invention, the circuit breaker includes: a first switching contact that opens and closes a direct-current electrical path; a semiconductor switch that is connected in series with the first switching contact; and a second switching contact that is connected to both ends of the semiconductor switch such that the second switching contact is in parallel with the semiconductor switch. When a closing operation is performed, the semiconductor switch is closed after the first switching contact and the second switching contact are closed, and when an interrupting operation is performed, the semiconductor switch is opened after the first switching contact and the second switching contact are opened. Therefore, it is possible to reliably interrupt direct current ranging from a low current to a fault current.

Brief Description of Drawings

[0009]

FIG. 1 is a circuit diagram illustrating the configuration of a circuit breaker according to a first embodiment of the present invention.
FIG. 2 is a circuit diagram illustrating the configuration of a circuit breaker according to a second embodiment of the present invention.
FIG. 3 is a configuration diagram schematically illustrating the configuration of the circuit breaker according to the second embodiment of the present invention.
FIG. 4 is a circuit diagram illustrating the configuration of a circuit breaker according to a third embodiment of the present invention.
FIG. 5 is a front view illustrating the circuit breaker

according to the third embodiment of the present invention.

FIG. 6 is a cross-sectional view taken along line x-x in FIG. 4.

FIG. 7 is a cross-sectional view taken along line y-y in FIG. 4.

FIG. 8 is an explanatory diagram for explaining operations of first switching contacts, second switching contacts, a crossbar, and actuators in FIG. 7, where (a) indicates an OFF state, (b) indicates a state during transition from an OFF state to an ON state, and (c) indicates an ON state.

Description of Embodiments

[0010] FIG. 1 is a circuit diagram illustrating the configuration of a circuit breaker according to a first embodiment of the present invention.

[0011] In FIG. 1, a circuit breaker 100 includes first switching contacts 1a and 1b, which are connected to a direct-current electrical path 200 and open and close the direct-current electrical path 200; second switching contacts 2a and 2b, which are connected in series with the first switching contacts 1a and 1b, respectively, and open and close the direct-current electrical path 200; a switching mechanism 3, which opens and closes the first switching contacts 1a and 1b and the second switching contacts 2a and 2b; semiconductor switches 4a and 4b, which open and close the direct-current electrical path 200 and which are connected to both ends of the second switching contacts 2a and 2b, respectively, such that the semiconductor switches 4a and 4b are in parallel with the second switching contacts 2a and 2b, respectively; trippers 5a and 5b, which, when the current flowing in the direct-current electrical path 200 exceeds a predetermined value, drive the switching mechanism 3 for a time period corresponding to the value of the current, thereby interrupting the first switching contacts 1a and 1b; and a gate drive circuit 6, which is connected to the load side of the tripper 5a and the load side of the tripper 5b and drives the semiconductor switches 4a and 4b.

[0012] The second switching contacts 2a and 2b are opened and closed in conjunction with the opening and closing operation of the first switching contacts 1a and 1b.

[0013] In the semiconductor switch 4a, a semiconductor device 4a1 connected in anti-parallel with a diode 4a3 and a semiconductor device 4a2 connected in anti-parallel with a diode 4a4 are connected in series but with reversed polarities.

[0014] In the semiconductor switch 4b, a semiconductor device 4b1 connected in anti-parallel with a diode 4b3 and a semiconductor device 4b2 connected in anti-parallel with a diode 4b4 are connected in series but with reversed polarities.

[0015] Operations of the circuit breaker 100 will be described next. First, the closing operation of the circuit breaker 100 will be described.

[0016] When the switching mechanism 3 is operated to close the first switching contacts 1a and 1b and the second switching contacts 2a and 2b, the closing operation of the second switching contacts 2a and 2b is completed first, and then the closing operation of the first switching contacts 1a and 1b is completed. Consequently, the current in the direct-current electrical path 200 starts flowing in the circuit breaker 100.

[0017] Then, power is supplied to the gate drive circuit 6, which drives the semiconductor switches 4a and 4b, and thus the semiconductor switches 4a and 4b are driven by the gate drive circuit 6 and turned on. Consequently, the closing operation of the first switching contacts 1a and 1b, the second switching contacts 2a and 2b, and the semiconductor switches 4a and 4b is completed. At this point in time, because the on-resistance of the semiconductor switches 4a and 4b is larger than the on-resistance of the second switching contacts 2a and 2b, the current substantially flows in the second switching contacts 2a and 2b.

[0018] The interrupting operation of the circuit breaker 100 will be described next.

[0019] The switching mechanism 3 is driven by an operation switch (not illustrated) or by the trippers 5a and 5b and the opening operation of the first switching contacts 1a and 1b is started first. When the first switching contacts 1a and 1b are opened, an arc is generated between the contacts of each of the first switching contacts 1a and 1b and the current that flows between the contacts of each of the first switching contacts 1a and 1b is limited.

[0020] When the opening operation of the first switching contacts 1a and 1b further proceeds, the opening operation of the second switching contacts 2a and 2b is also started. When the second switching contacts 2a and 2b are opened, an arc is also generated between the contacts of each of the second switching contacts 2a and 2b and thus the voltage across the contacts of each of the second switching contacts 2a and 2b increases. Accordingly, the current that flows between the contacts of each of the first switching contacts 1a and 1b and between the contacts of each of the second switching contacts 2a and 2b is further limited, and the currents flowing in the second switching contacts 2a and 2b are diverted to the semiconductor switches 4a and 4b, respectively. Then, when a predetermined period of time (for example, 15 msec) has elapsed since the first switching contacts 1a and 1b and the second switching contacts 2a and 2b were opened and the flowing current is sufficiently limited, the gate drive circuit 6 stops the driving of the gates of the semiconductor switches 4a and 4b so as to turn off the semiconductor switches 4a and 4b, and thereby interruption of the direct-current electrical path 200 is completed.

[0021] It is possible to achieve, in accordance with a signal from the switching mechanism 3, a delay operation to stop the driving of the gates of the semiconductor switches 4a and 4b by the gate drive circuit 6 after the second switching contacts 2a and 2b are opened. Because the generation of an arc between the contacts of each of the first switching contacts 1a and 1b and the generation of an arc between the contacts of each of the second switching contacts 2a and 2b cause the voltage across the contacts to increase and thus cause the voltage applied to the gate drive circuit 6 to drop, as an alternative, it is possible to configure a circuit for the delay operation on the basis of this voltage drop.

[0022] In the circuit diagram illustrated in FIG. 1, the first switching contacts 1a and 1b are placed on the side where the direct-current electrical path 200 is located and the second switching contacts 2a and 2b are placed on the side where a load 300 is located; however, the first switching contacts 1a and 1b may be placed on the side where the load 300 is located and the second switching contacts 2a and 2b may be placed on the side where the direct-current electrical path 200 is located. It is desirable that the gate drive circuit 6 be placed closer to the load 300 than the first switching contacts 1a and 1b and the second switching contacts 2a and 2b. Moreover, if a reverse connection of the power supply and the load is taken into consideration, it is desirable to have a configuration in which the gate drive circuit 6 is placed between the first switching contacts 1a and 1b and the second switching contacts 2a and 2b so as to enable the interruption of power supply to the gate drive circuit 6 in any of a normal connection and a reverse connection.

[0023] According to the present embodiment, the following are provided: the first switching contacts 1a and 1b, which open and close the direct-current electrical path 200; the semiconductor switches 4a and 4b, which are connected in series with the first switching contacts 1a and 1b, respectively; and the second switching contacts 2a and 2b, which are connected to both ends of the semiconductor switches 4a and 4b, respectively, such that the second switching contacts 2a and 2b are in parallel with the semiconductor switches 4a and 4b, respectively. When the closing operation is performed, the semiconductor switches 4a and 4b are closed after the first switching contacts 1a and 1b and the second switching contacts 2a and 2b are closed. When the interrupting operation is performed, the semiconductor switches 4a and 4b are opened after the first switching contacts 1a and 1b and the second switching contacts 2a and 2b are opened. Therefore, direct current ranging from a low current to a ground-fault current can be reliably interrupted.

[0024] Moreover, the switching mechanism 3 is provided, which closes the second switching contacts 2a and 2b before closing the first switching contacts 1a and 1b and opens the second switching contacts 2a and 2b after opening the first switching contacts 1a and 1b; therefore, an interrupting current flowing during the interrupting operation is diverted from the second switching contacts 2a and 2b to the semiconductor switches 4a and 4b after it is sufficiently limited due to the opening of the first switching contacts 1a and 1b. This eliminates the concern that the semiconductor switches 4a and 4b may be damaged.

Second embodiment.

[0025] FIG. 2 is a circuit diagram illustrating the configuration of a circuit breaker according to a second embodiment of the present invention. FIG. 3 is a configuration diagram schematically illustrating the configuration of the circuit breaker according to the second embodiment of the present invention.

[0026] FIGS. 2 and 3 illustrate a circuit breaker 101, which is a four-pole circuit breaker that includes a pole 11, which is connected at one end to the positive pole of the direct-current electrical path 200 and includes a first switching contact 11a; a pole 12, which is connected at one end to the negative pole of the direct-current electrical path 200 and includes a first switching contact 12a; a pole 13, which is connected at one end to the other end of the pole 11 and includes a second switching contact 13a; a pole 14, which is connected at one end to the other end of the pole 12 and includes a second switching contact 14a; a semiconductor switch 15a, which is connected between the other ends of the pole 11 and the pole 13; a semiconductor switch 15b, which is connected between the other ends of the pole 12 and the pole 14; a switching mechanism 3a, which opens and closes the first switching contacts 11a and 12a and the second switching contacts 13a and 14a; and a gate drive circuit 6a, which is connected between the other ends of the pole 11 and the pole 12 and drives the gates of the semiconductor switches 15a and 15b. The load 300 is connected to the other ends of the poles 13 and 14.

[0027] A tripper 11b is placed between the first switching contact 11a and the other end of the pole 11; a tripper 12b is placed between the first switching contact 12a and the other end of the pole 12; a tripper 13b is placed between the second switching contact 13a and the other end of the pole 13; and a tripper 14b is placed between the second switching contact 14a and the other end of the pole 14. The semiconductor switches 15a and 15b have the same configuration as that of the semiconductor switches 4a and 4b described in the first embodiment and thus any description thereof will be omitted.

[0028] The opening distance of the first switching contacts 11a and 12a is set to be larger than the opening distance of the second switching contacts 13a and 14a. Due to the difference in the opening distance, the second switching contacts 13a and 14a are closed before the first switching contacts 11a and 12a are closed in the closing operation, and the second switching contacts 13a and 14a are opened after the first switching contacts 11a and 12a are opened in an interrupting operation.

[0029] Operations of the circuit breaker 101 will be described next. First, the closing operation of the circuit breaker 101 will be described.

[0030] When the switching mechanism 3a is operated to close the first switching contacts 11a and 12a and the second switching contacts 13a and 14a, because the opening distance of the second switching contacts 13a and 14a is smaller than the opening distance of the first switching contacts 11a and 12a, the closing operation of the second switching contacts 13a and 14a is completed first, and then the closing operation of the first switching contacts 11a and 12a is completed. Consequently, the current in the direct-current electrical path 200 starts flowing in the circuit breaker 101.

[0031] Then, power is supplied to the gate drive circuit 6a, which drives the semiconductor switches 15a and 15b, and thus the semiconductor switches 15a and 15b are driven by the gate drive circuit 6a and turned on. Consequently, the closing operation of the first switching contacts 11a and 12a, the second switching contacts 13a and 14a, and the semiconductor switches 15a and 15b is completed. At this point in time, because the on-resistance of the semiconductor switches 15a and 15b is larger than the on-resistance of the second switching contacts 13a and 14a, the current substantially flows in the second switching contacts 13a and 14a.

[0032] The interrupting operation of the circuit breaker 101 will be described next.

[0033] The switching mechanism 3a is driven by an operation switch (not illustrated) or by the trippers 11b, 12b, 13b, and 14b and the opening operation of the first switching contacts 11a and 12a is started first. When the first switching contacts 11a and 12a are opened, an arc is generated between the contacts of each of the first switching contacts 11a and 12a and the current that flows between the contacts of each of the first switching contacts 11a and 12a is limited.

[0034] When the opening operation of the first switching contacts 11a and 12a further proceeds, the opening operation of the second switching contacts 13a and 14a is also started and an arc is generated between the contacts of each of the second switching contacts 13a and 14a; therefore, the voltage across the contacts of each of the second switching contacts 13a and 14a increases. Due to the increase of the voltage across the contacts of each switching contact, the currents flowing in the second switching contacts 13a and 14a are diverted to the semiconductor switches 15a and 15b, respectively. Then, when a predetermined period of time (for example, 15 msec) or longer has elapsed since the first switching contacts 11a and 12a and the second switching contacts 13a and 14a were opened and the flowing current is sufficiently limited, the gate drive circuit 6a stops the driving of the gates of the semiconductor switches 15a and 15b so as to turn off the semiconductor switches 15a and 15b, and thereby interruption of the direct-current electrical path 200 is completed.

[0035] In the present embodiment, the switching contacts 11a and 12a in the poles 11 and 12 connected at their ends on one side to the direct-current electrical path 200 are referred to as a first switching contact in the claims and the switching contacts 13a and 14a in the poles 13 and 14 connected at their ends on the other side to the load 300 are referred to as a second switching contact in the claims; however, the switching contacts 11a and 12a may be referred to as a second switching contact and the switching contacts 13a and 14a may be referred to as a first switching contact. In such a case, the opening distance of the switching contacts 11a and 12a is set to be smaller than the opening distance of the switching contacts 13a and 14a.

[0036] According to the present embodiment, the following are provided: the first switching contacts 11a and 12a, which open and close the direct-current electrical path 200; the semiconductor switches 15a and 14b, which are connected in series with the first switching contacts 11a and 12a, respectively; and the second switching contacts 13a and 14a, which are connected to both ends of the semiconductor switches 15a and 14b, respectively, such that the second switching contacts 13a and 14a are in parallel with the semiconductor switches 15a and 14b, respectively. When the closing operation is performed, the semiconductor switches 15a and 14b are closed after the first switching contacts 11a and 12a and the second switching contacts 13a and 14a are closed. When the interrupting operation is performed, the semiconductor switches 15a and 14b are opened after the first switching contacts 11a and 12a and the second switching contacts 13a and 14a are opened. Therefore, direct current ranging from a low current to a ground-fault current can be reliably interrupted.

[0037] Moreover, the switching mechanism 3a is provided, which closes the second switching contacts 13a and 14a before closing the first switching contacts 11a and 12a and opens the second switching contacts 13a and 14a after opening the first switching contacts 11a and 12a; therefore, an interrupting current flowing during the interrupting operation is diverted from the second switching contacts 13a and 14a to the semiconductor switches 15a and 15b after it is sufficiently limited due to the opening of the first switching contacts 11a and 12a. This eliminates the concern that the semiconductor switches 15a and 15b may be damaged.

[0038] The opening distance of the first switching contacts 11a and 12a is larger than the opening distance of the second switching contacts 13a and 14a; therefore, the second switching contacts 13a and 14a are closed before the first switching contacts 11a and 12a are closed and the second switching contacts 13a and 14a are opened after the first switching contacts 11a and 12a are opened. Thus, the existing switching mechanism 3a can be used.

Third embodiment.

[0039] FIG. 4 is a circuit diagram illustrating the configuration of the circuit breaker according to the second embodiment of the present invention; FIG. 5 is a front view illustrating a circuit breaker according to a third embodiment of the present invention; FIG. 6 is a cross-sectional view taken along line x-x in FIG. 4; FIG. 7 is a cross-sectional view taken along line y-y in FIG. 4; and FIG. 8 is an explanatory diagram for explaining operations of first switching contacts, second switching contacts, a crossbar, and actuators in FIG. 7, where (a) indicates an OFF state, (b) indicates a state during transition from an OFF state to an ON state, and (c) indicates an ON state.

[0040] FIG. 4 illustrates a circuit breaker 102, which is a four-pole circuit breaker that includes a pole 41, which is connected at one end to the positive pole of the direct-current electrical path 200 and includes a first switching contact 41a; a pole 42, which is connected at one end to the negative pole of the direct-current electrical path 200 and includes a first switching contact 42a; a pole 43, which is connected at one end to the positive pole of the load 300 and includes a first switching contact 43a; a pole 44, which is connected at one end to the negative pole of the load 300 and includes a first switching contact 44a; a semiconductor switch 45a, which is connected between the other ends of the pole 41 and the pole 43; a semiconductor switch 45b, which is connected between the other ends of the pole 42 and the pole 44; and a switching mechanism 30, which opens and closes the first switching contacts 41a, 42a, 43a, and 44a.

[0041] A tripper 41b is placed between the first switching contact 41a and the other end of the pole 41; a tripper 42b is placed between the first switching contact 42a and the other end of the pole 42; a tripper 43b is placed between the first switching contact 43a and the other end of the pole 43; and a tripper 44b is placed between the first switching contact 44a and the other end of the pole 44.

[0042] A second switching contact 46a is connected in parallel with the semiconductor switch 45a and between the other ends of the pole 41 and the pole 43, and a second switching contact 46b is connected in parallel with the semiconductor switch 45b and between the other ends of the pole 42 and the pole 44. The semiconductor switches 45a and 45b have the same configuration as that of the semiconductor switches 4a and 4b described in the first embodiment and thus any description thereof will be omitted.

[0043] The structure of the circuit breaker 102 will be described next. As illustrated in FIGS. 5 and 6, the circuit breaker 102 is configured with a casing 20, which includes a base 20a and a cover 20b made of an insulating material. The poles 41 to 44 are connected in parallel with each other and are placed on the base 20a. The switching mechanism 30, which includes a well-known toggle link mechanism, is placed above the poles 41 to 44. The cover 20b covers the poles on the base 20a and the switching mechanism 30, and an operating handle 31 of the switching mechanism 30 projects from a window 20b1 of the cover 20b.

[0044] The poles are all identically configured, and a crossbar 32 is placed on the base 20a such that the crossbar 32 is orthogonal to the poles 41 to 44.

[0045] Each of the poles includes a power-supply-side terminal 24 provided on the base 20a; a fixed contact 21 provided on a fixed contact part 27, which extends from the power-supply-side terminal 24; a movable contact 22, which comes into and out of contact with the fixed contact 21; a movable contact part 23, which is provided at one end with the movable contact 22 and is rotatably supported by the crossbar 32; the one of the trippers 41b, 42b, 43b, and 44b, to which the pole corresponds and which is connected to the movable contact part 23 by a movable contact part holder 26; and a load-side terminal 25, which is integral with the one of the trippers 41b, 42b, 43b, and 44b, to which the pole corresponds.

[0046] The fixed contact 21 and the movable contact 22 of each of the poles constitute the one of the first switching contacts 41a, 42a, 43a, and 44a, to which the pole corresponds and which is the contact to open or close the electrical path first when a high current is interrupted.

[0047] When the crossbar 32 rotates around its axial center, the movable contact parts 23 of the poles 41 to 44 rotate simultaneously. The rotation of the movable contact parts 23 causes the movable contacts 22 to come into and out of contact with the fixed contacts 21.

[0048] The switching mechanism 30 includes a well-known toggle link mechanism and a well-known trip bar 33 driven by the trippers 41b, 42b, 43b, and 44b.

[0049] Furthermore, as illustrated in FIG. 7, the circuit breaker 102 includes actuators 28a and 28b, which are provided on both sides of the switching mechanism 30 and are driven by the rotation of the crossbar 32; and second switching contacts 46a and 46b, which are provided on both sides of the switching mechanism 30 and are driven by the actuators 28a and 28b such that their contacts are opened and closed.

[0050] When a button 461 of the second switching contacts 46a and 46b is pressed by the actuators 28a and 28b, the switching contacts of each of the second switching contacts 46a and 46b come into contact with each other.

[0051] Operations of the circuit breaker 102 will be described next.

[0052] First, the closing operation will be described.

[0053] As illustrated in FIG. 8, when the operating handle 31 is operated and the toggle link of the switching mechanism 30 exceeds the dead point, the crossbar 32 starts rotating counterclockwise on the paper surface of FIG. 8 to transition from the state in FIG. 8(a) to the state in FIG. 8(b). The rotation of the crossbar 32 causes the actuators 28a and 28b to rotate counterclockwise on the paper surface of FIG. 8 and thus the button 461 is pressed by the actuators 28a and 28b as illustrated in FIG. 8(b). Due to the pressing of the button 461, the second switching contacts 46a and 46b enter the contact state.

[0054] When the crossbar 32 further rotates, as illustrated in FIG. 8(c), the movable contacts 22 come into contact with the fixed contacts 21, with the movable contacts 22 and the fixed contacts 21 constituting the first switching contacts 41a, 42a, 43a, and 44a. Consequently, the voltage of the direct-current electrical path 200 is applied to the gate drive circuit 6 and the semiconductor switches 45a and 45b are turned on after a predetermined delay time. Although the semiconductor switches

45a and 45b are kept in an on state, because the contact resistance of the second switching contacts 46a and 46b is lower than the on-resistance of the semiconductor switches 45a and 45b, the current mainly flows in the second switching contacts 46a and 46b. Thus, heat generation by the semiconductor switches 45a and 45b is suppressed.

[0055] The interrupting operation will be described next.

[0056] When a short-circuit current or an overcurrent flows, the trippers 41b, 42b, 43b, and 44b press the trip bar 33 and thus the switching mechanism 30 is driven. Consequently, the crossbar 32 starts rotating. The rotation of the crossbar 32 causes the movable contacts 22 to be separated from the fixed contacts 21. Thus, the first switching contacts 41a, 42a, 43a, and 44a are opened first. When the movable contacts 22 are separated, an arc current attempts to maintain the shortest distance between the fixed contacts 21 and the movable contacts 22 because the direct-current voltage is sufficiently high with respect to the opening distance. Because the voltage is in some cases too high to be interrupted only by using an arc-extinguishing device 50, the purpose of the first switching contacts in the embodiments is to limit the interrupting current when a high current is to be interrupted. The arc-extinguishing device 50 is configured such that the first switching contacts are opened simultaneously with the start of the rotation of the crossbar 32 and the current is reduced to a current lower than or equal to the rated current of the semiconductor switches 45a and 45b by the time immediately before the opening distance becomes maximum.

[0057] Thereafter, the second switching contacts 46a and 46b are opened immediately before the opening distance of the crossbar 32 becomes maximum and the current thus limited is diverted to the semiconductor switches 45a and 45b. At this point in time, the current is limited also between the contacts of each of the first switching contacts 41a, 42a, 43a, and 44a and the voltage drop is also large; therefore, the supply voltage to the gate drive circuit 6, which drives the semiconductor switches 45a and 45b, drops. The supply voltage drop causes power feeding to the gate drive circuit 6 to be stopped; however, due to a delay circuit of the gate drive circuit 6, the gate voltage of the semiconductor switches 45a and 45b is maintained for a predetermined period of time (for example, 15 msec). Then, after the elapse of the predetermined period of time, when the flowing current falls below or equal to the rated current, the gates of the semiconductor switches 45a and 45b are turned off so as to complete the interrupting operation.

[0058] According to the present embodiment, the following are provided: the first switching contacts 41a, 42a, 43a, and 44a, which open and close the direct-current electrical path 200; the semiconductor switches 45a and 45b, which are connected in series with the first switching contacts 41a, 42a, 43a, and 44a; and the second switching contacts 46a and 46b, which are connected to both ends of the semiconductor switches 45a and 45b, respectively, such that the second switching contacts 46a and 46b are in parallel with the semiconductor switches 45a and 45b, respectively. When the closing operation is performed, the semiconductor switches 45a and 45b are closed after the first switching contacts 41a, 42a, 43a, and 44a and the second switching contacts 46a and 46b are closed. When the interrupting operation is performed, the semiconductor switches 45a and 45b are opened after the first switching contacts 41a, 42a, 43a, and 44a and the second switching contacts 46a and 46b are opened. Therefore, direct current ranging from a low current to a ground-fault current can be reliably interrupted.

[0059] The fixed contacts 21 and the movable contacts 22, which come into and out of contact with the fixed contacts 21, are provided for four poles, i.e., four systems, with the fixed contact 21 and the movable contact 22 constituting the first switching contact; therefore, it is possible to interrupt a direct-current circuit that is for a higher voltage than the case where the first switching contacts are provided for two systems.

Reference Signs List

[0060] 1a first switching contact; 1b first switching contact; 2a second switching contact; 2b second switching contact; 3 switching mechanism; 4a semiconductor switch; 4b semiconductor switch; 5a tripper; 5b tripper; 100 circuit breaker.

Claims

1. A circuit breaker comprising:

    a first switching contact that opens and closes an electrical path;
    a second switching contact that is connected in series with the first switching contact and opens and closes the electrical path; and
    a semiconductor switch that is connected to both ends of the second switching contact such that the semiconductor switch is in parallel with the second switching contact and that opens and closes the electrical path, wherein
    when a closing operation is performed, the semiconductor switch is closed after the first switching contact and the second switching contact are closed, and
    when an interrupting operation is performed, the semiconductor switch is opened after the first switching contact and the second switching contact are opened.

2. The circuit breaker according to claim 1, further comprising a switching mechanism that closes the second switching contact before closing the first switching contact and opens the second switching contact

after opening the first switching contact.

3. The circuit breaker according to claim 1 or 2, wherein the circuit breaker is a four-pole circuit breaker, two poles are provided with the first switching contact, with each of the two poles being connected at one end to any of the electrical path and a load, and another two poles are provided with the second switching contact, with each of the another two poles being connected at one end to another end of a corresponding one of the two poles and one end of the semiconductor switch and being connected at another end to another end of the semiconductor switch.

4. The circuit breaker according to claim 3, wherein an opening distance of the first switching contact is larger than an opening distance of the second switching contact.

5. The circuit breaker according to claim 2, wherein the circuit breaker is a four-pole circuit breaker, two poles are provided with the first switching contact, with the two poles being connected at ends on one side to a positive pole and a negative pole of the electrical path, respectively, another two poles are provided with the first switching contact, with the another two poles being connected at ends on one side to a positive pole and a negative pole of a load, respectively, the semiconductor switch is connected between ends on another side of the two poles and between ends on another side of the another two poles, and the second switching contact is provided on both sides of the switching mechanism in a direction in which the poles of the switching mechanism are arranged, and is connected between both ends of the semiconductor switch such that the second switching contact is in parallel with the semiconductor switch.

6. The circuit breaker according to claim 5, further comprising an actuator that is driven by the switching mechanism and opens and closes the second switching contact.

FIG.1

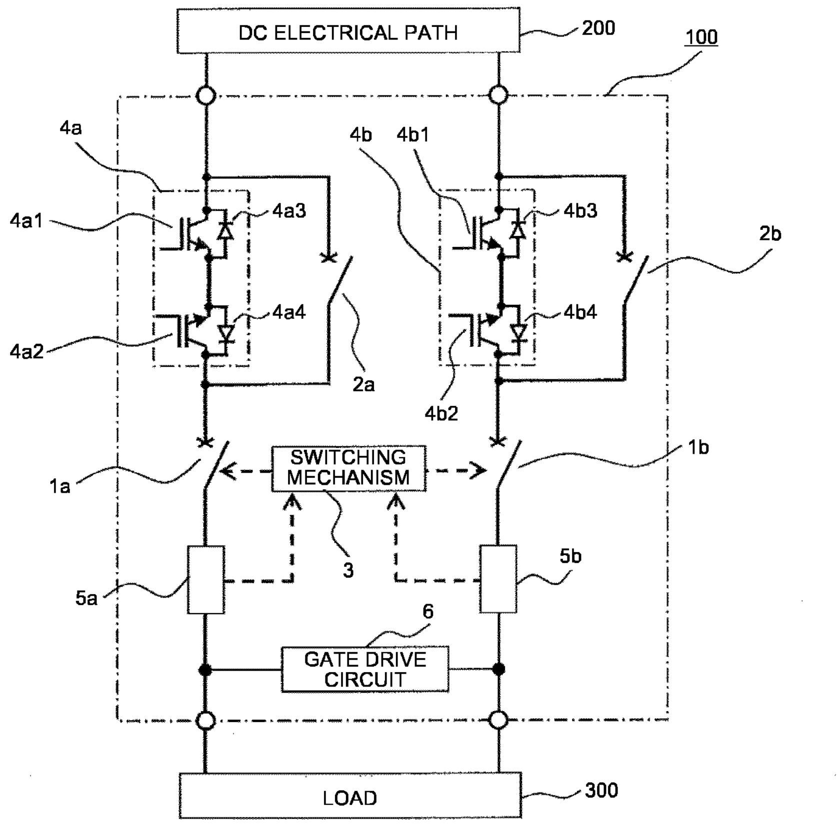

DC ELECTRICAL PATH
200
100
4a
4b
4b1
4a1
4a3
4b3
2b
4a4
4b4
4a2
2a
4b2
1b
1a
SWITCHING MECHANISM
3
5a
5b
6
GATE DRIVE CIRCUIT
LOAD
300

FIG.2

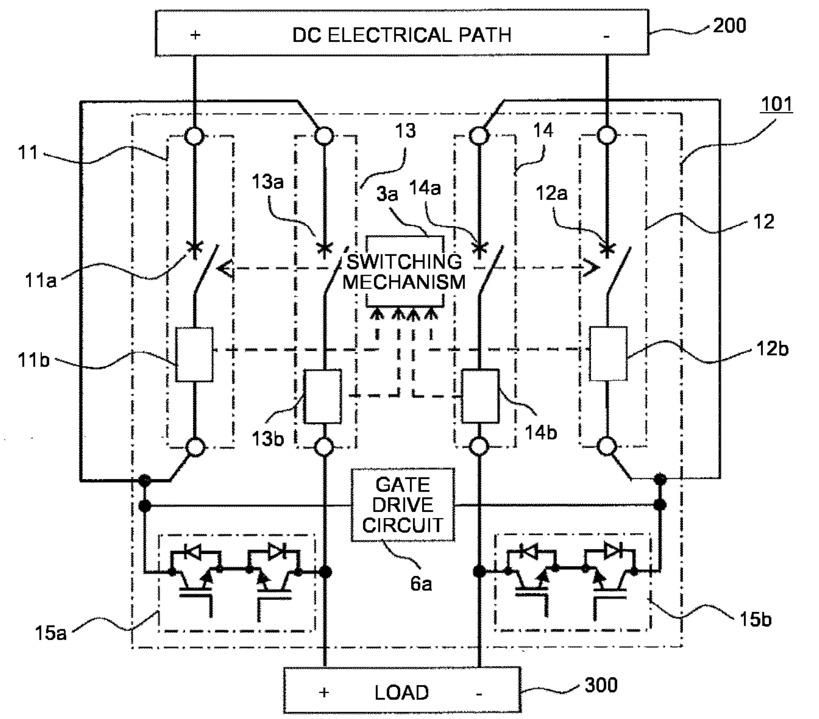

+
DC ELECTRICAL PATH
-
200
101
13
14
11
13a
3a
14a
12a
12
11a
SWITCHING MECHANISM
11b
12b
13b
14b
GATE DRIVE CIRCUIT
6a
15a
15b
+
LOAD
-
300

FIG.3

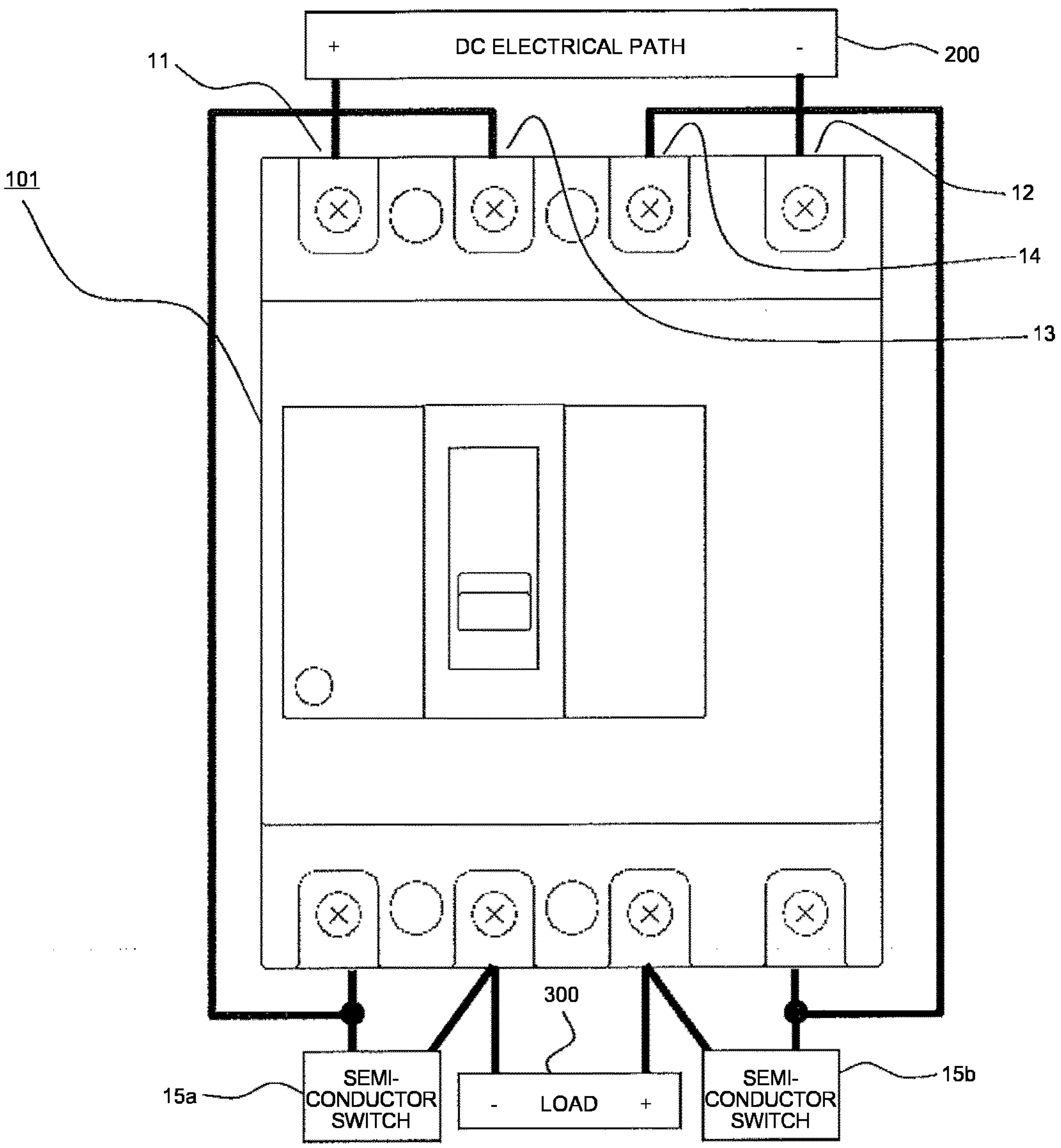
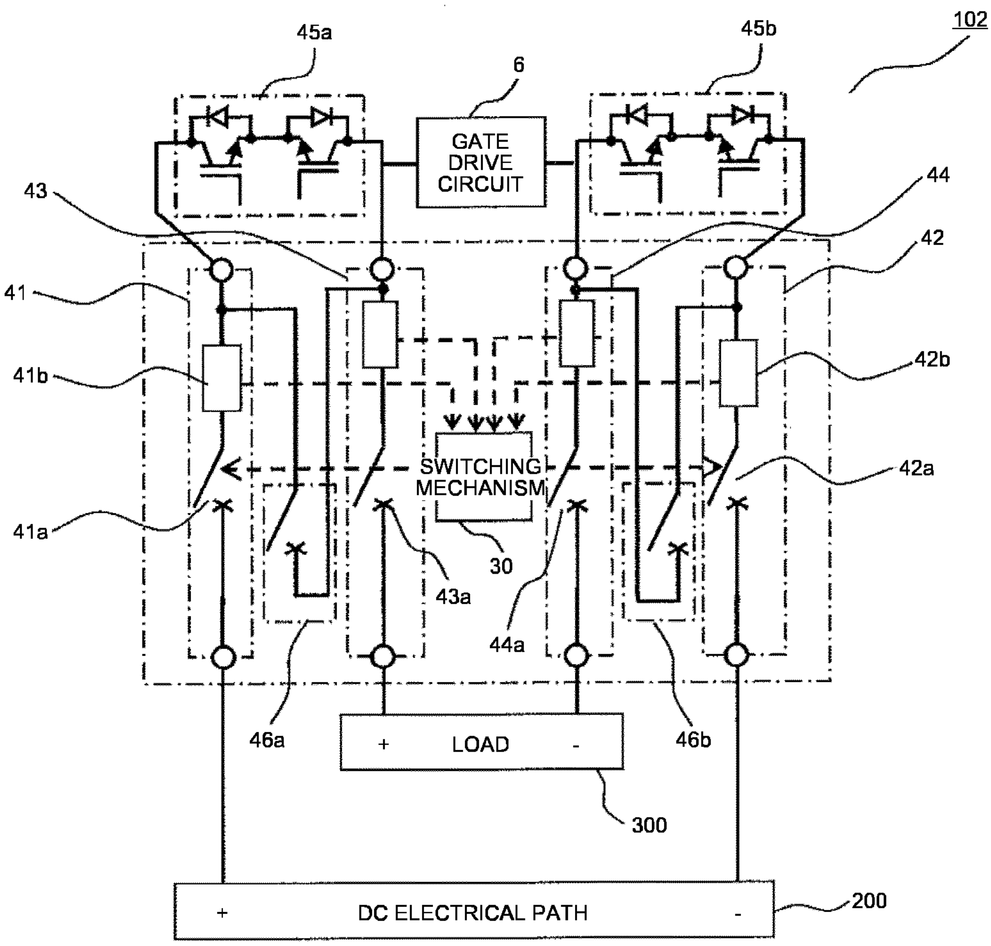

+
DC ELECTRICAL PATH
-
200
11
101
12
14
13
300
SEMI-
CONDUCTOR
SWITCH
15a
-
LOAD
+
SEMI-
CONDUCTOR
SWITCH
15b

FIG.4



102
45a
45b
6
GATE
DRIVE
CIRCUIT
43
44
41
42
41b
42b
SWITCHING
MECHANISM
42a
41a
30
43a
44a
46a
46b
+
LOAD
-
300
+
DC ELECTRICAL PATH
-
200

FIG.5

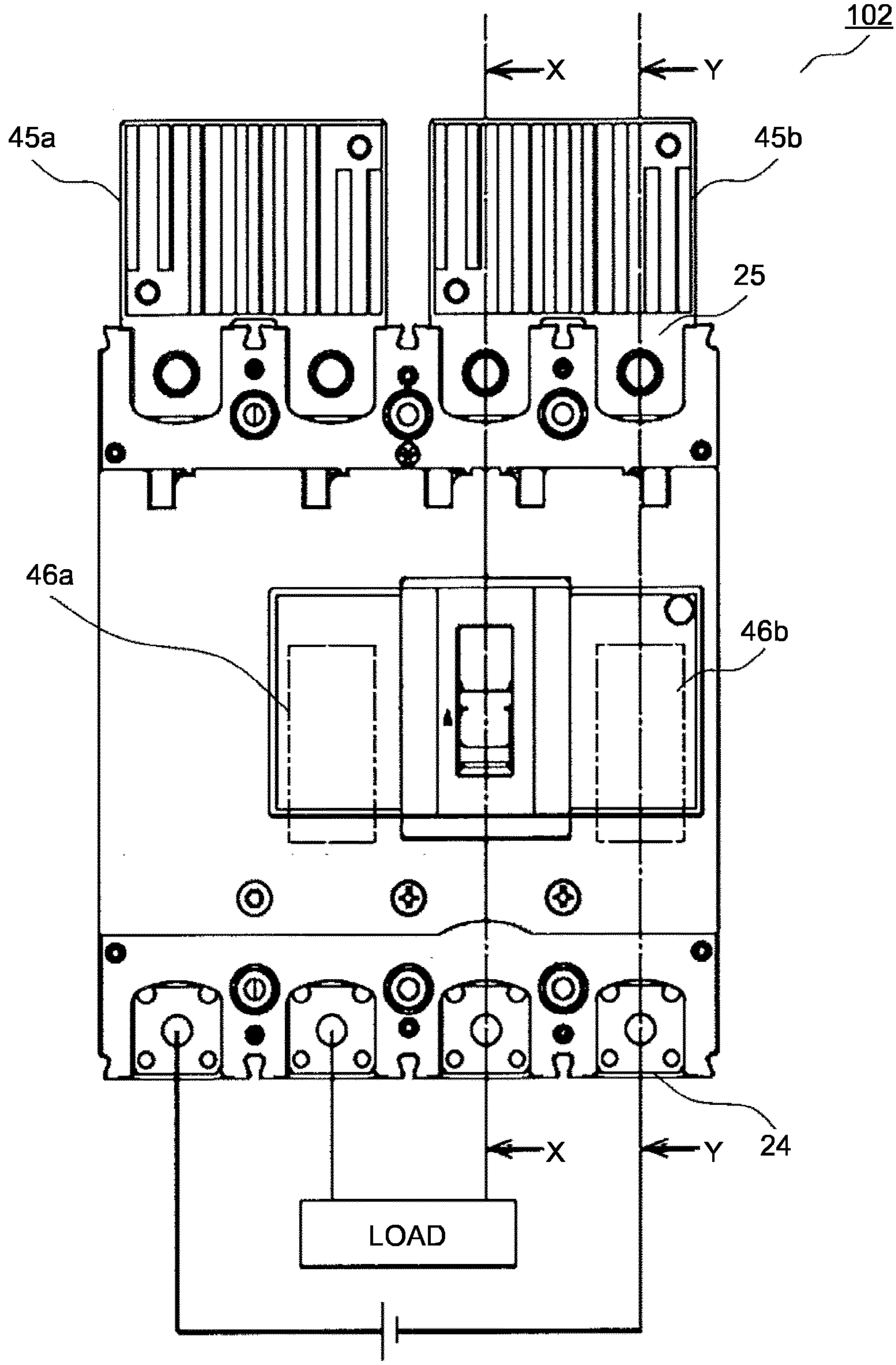


FIG.6

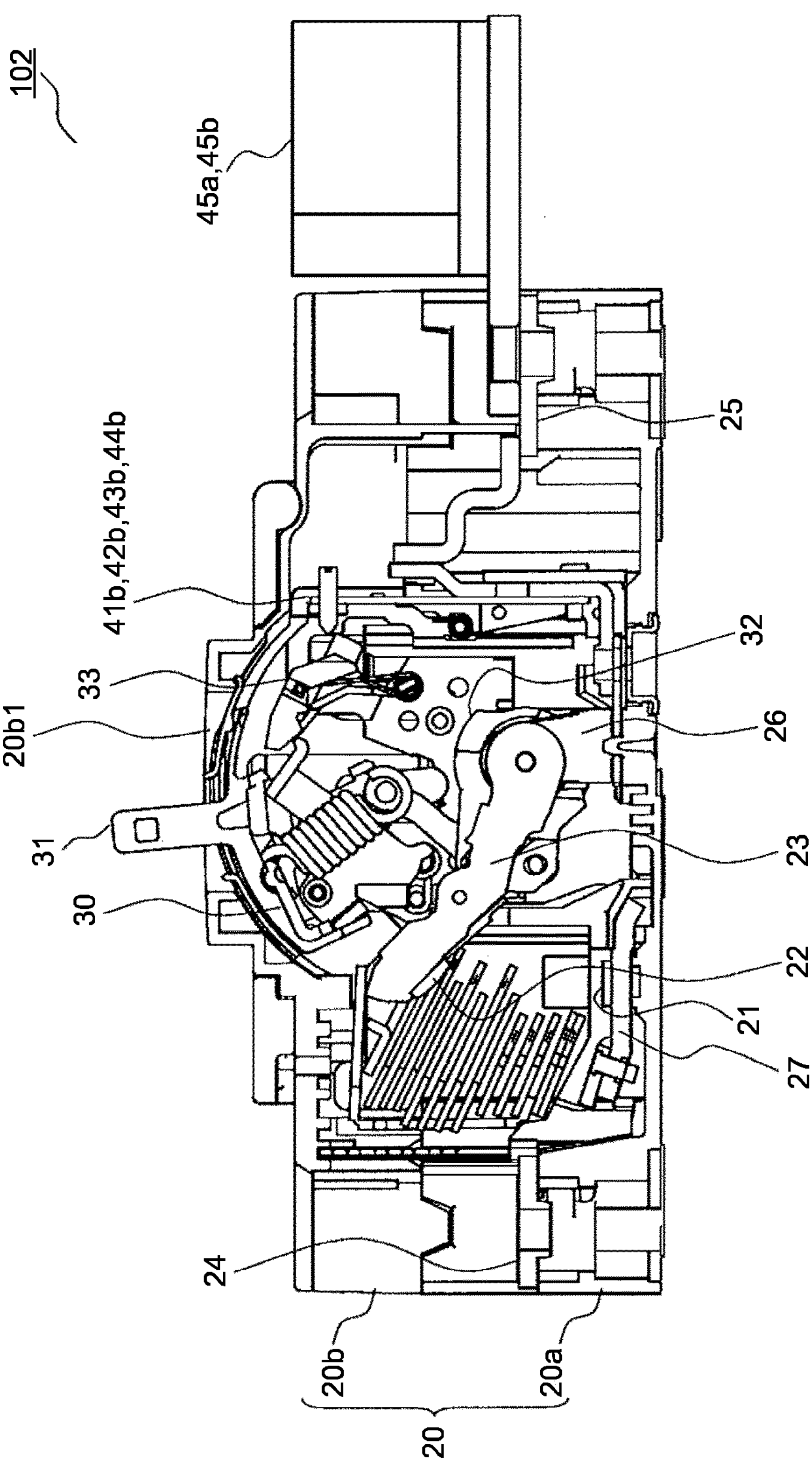

102
45a,45b
41b,42b,43b,44b
33
20b1
31
30
25
32
26
23
22
21
27
24
20b
20a
20

FIG.7

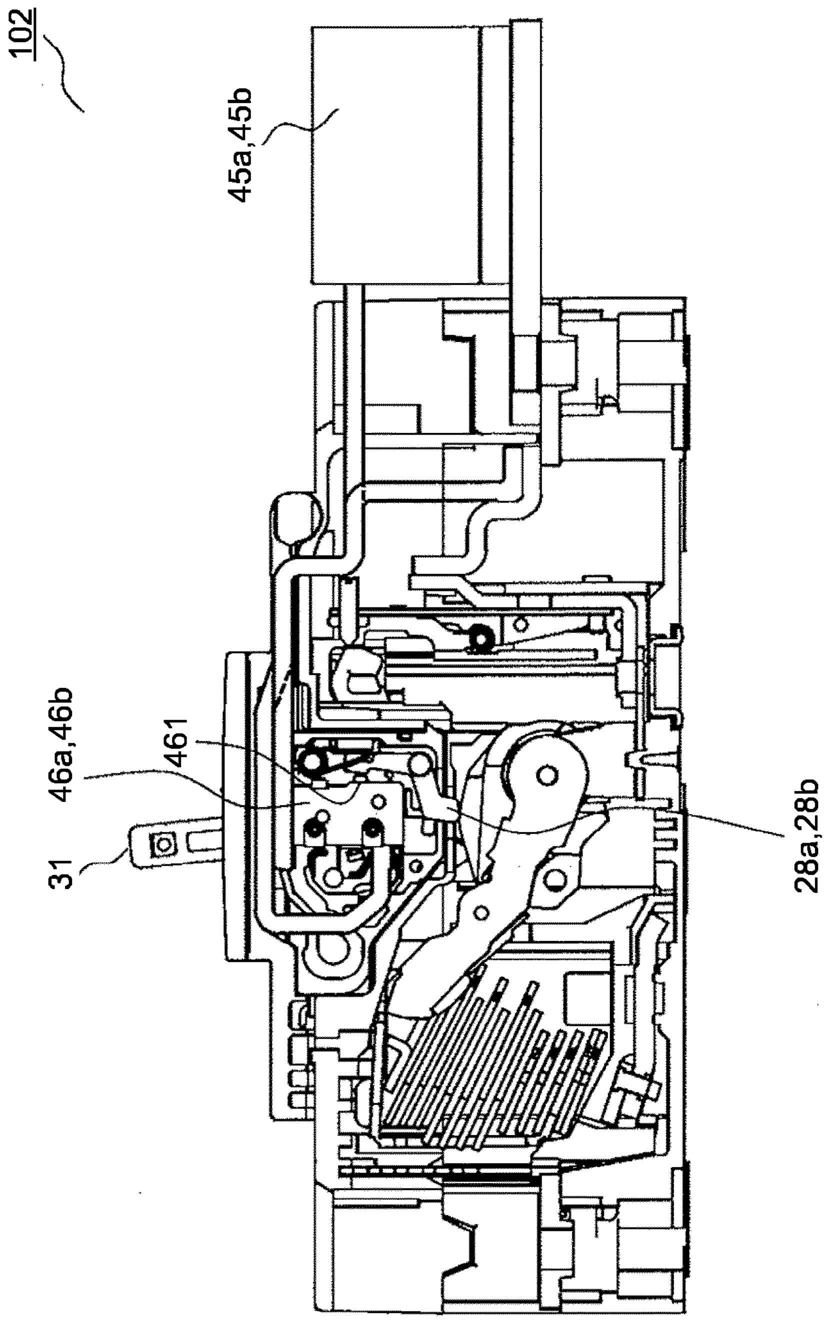
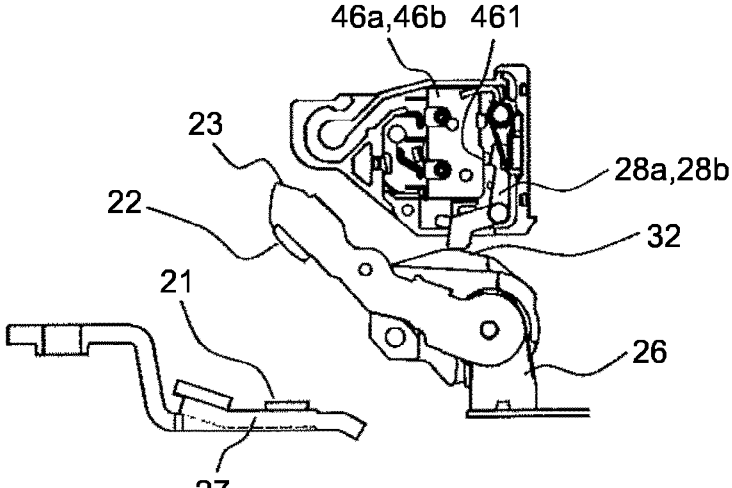
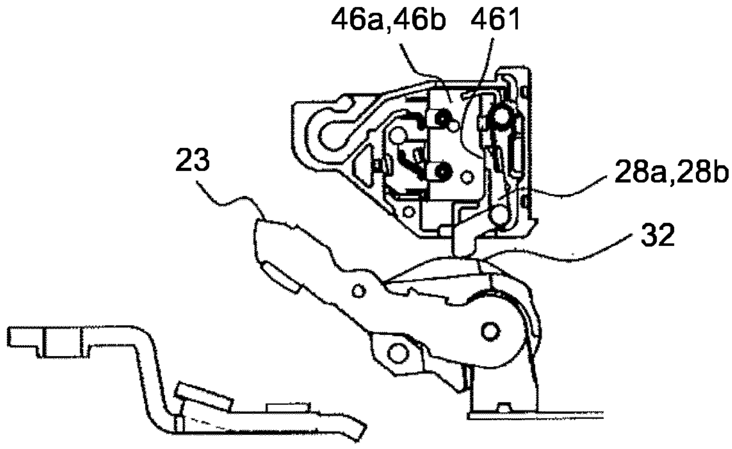


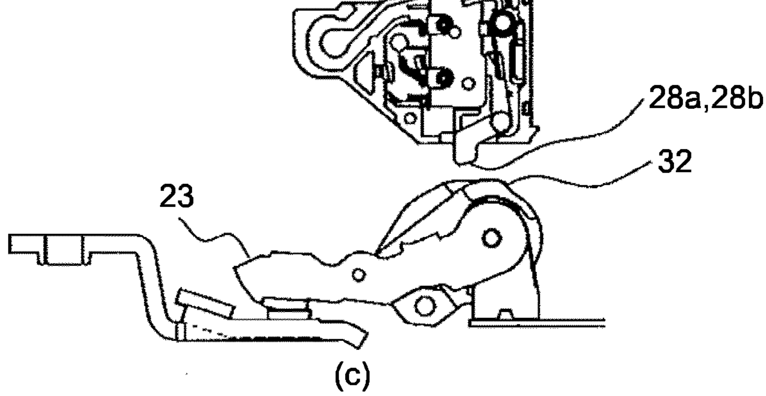
FIG.8


46a,46b
461
23
28a,28b
22
32
21
26
27

(a)


46a,46b
461
23
28a,28b
32

(b)


28a,28b
32
23

(c)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/076243

A. CLASSIFICATION OF SUBJECT MATTER
H01H33/59(2006.01)i, *H01H73/18*(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, H01H73/18

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	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

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 A	JP 2002-93294 A (Toshiba Corp.), 29 March 2002 (29.03.2002), paragraphs [0017] to [0028]; fig. 9 (Family: none)	1 2-6
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)	1

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

* Special categories of cited documents:
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"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
02 December 2015 (02.12.15)	15 December 2015 (15.12.15)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/076243

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 2014-241187 A (Fuji Electric Co., Ltd.), 25 December 2014 (25.12.2014), paragraph [0034]; fig. 7 (Family: none)	1
A	JP 8-106839 A (Alps Electric Co., Ltd.), 23 April 1996 (23.04.1996), entire text; all drawings (Family: none)	1-6
A	JP 2012-248445 A (Fuji Electric Co., Ltd.), 13 December 2012 (13.12.2012), entire text; all drawings (Family: none)	1-6
A	JP 10-334785 A (Mitsubishi Electric Corp.), 18 December 1998 (18.12.1998), paragraph [0008]; fig. 27 (Family: none)	3-6

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2012248445 A **[0004]**
- JP 2014038775 A **[0004]**