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(71) Applicant: **Kabushiki Kaisha Toshiba**
Minato-ku
Tokyo 105-8001 (JP)

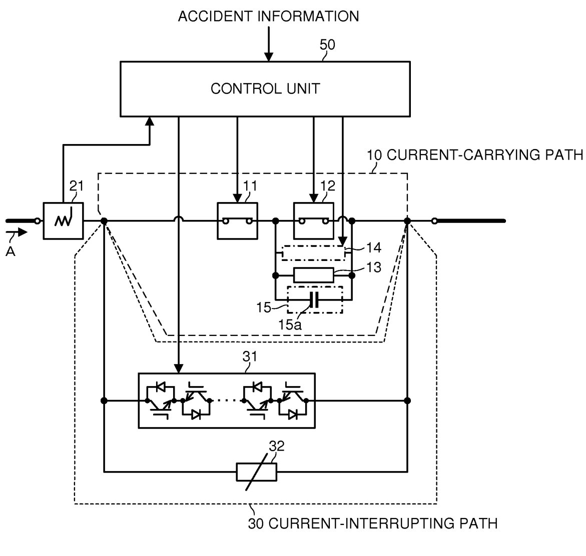
(72) Inventors:
- **NIWA, Yoshimitsu**
  Tokyo 105-8001 (JP)
- **ANDO, Masayuki**
  Tokyo 105-8001 (JP)
- **SAKAGUCHI, Wataru**
  Tokyo 105-8001 (JP)
- **HASEGAWA, Tetsuya**
  Tokyo 105-8001 (JP)
- **OOSHIMA, Takashi**
  Tokyo 105-8001 (JP)
- **DAIBO, Akira**
  Tokyo 105-8001 (JP)

(74) Representative: **Awapatent AB**
P.O. Box 11394
404 28 Göteborg (SE)

(54) **DIRECT CURRENT INTERRUPTION DEVICE**

(57) A direct-current interrupter of an embodiment includes: a current-carrying path; a commutation circuit; a semiconductor circuit breaker; and a non-linear resistor. The current-carrying path passes a direct current and includes first and second switches. The second switch is connected in series to the first switch and has a withstand voltage lower than a withstand voltage of the first switch. The semiconductor circuit breaker and the non-linear resistor are connected in parallel to the current-carrying path.

FIG. 1



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Description

FIELD

[0001] Embodiments of the present invention relate to a direct-current interrupter for interrupting a direct current.

BACKGROUND

[0002] A transmission system for transmitting power is generally required to have a function of interrupting a transmitted current in order to deal with an accident or the like. An interrupter is used for this purpose.

[0003] Since an alternating current has a time (current zero point) at which current becomes "0" (zero), the current can be interrupted relatively easily at this current zero point. On the other hand, different from the alternating current, a direct current has no current zero point, and therefore an interruption of the current easily causes an arc. Therefore, direct-current interrupters generally have a mechanism to reduce the arc.

[0004] The direct-current interrupter has a current-carrying path having a switch, and a current-interrupting path connected in parallel to the current-carrying path and capable of gradually decreasing current, for example.

[0005] At normal time, the switch on the current-carrying path is closed to pass current through the current-carrying path. On the other hand, at accident time, by making current flow through the current-interrupting path temporarily and opening the switch, a path of current is switched from the current-carrying path to the current-interrupting path to pass the current through the current-interrupting path (commutation). Thereafter, the current through the current-interrupting path is immediately decreased to interrupt the current.

[0006] Here, switching of the current from the current-carrying path to the current-interrupting path is preferably fast. When the switching is slow, a current at accident time increases, and the current which the current-interrupting path is to interrupt becomes large. Consequently, a current-interrupting path with a large capacity is required, and there is a possibility that the interrupter increases in size.

PRIOR ART DOCUMENT

NON-PATENT DOCUMENT

[0007]

Non-Patent Document 1: Juergen Haefner, Bjoern Jacobson, "Proactive Hybrid HVDC Breakers - A key innovation for reliable HVDC grids", Cigre, The electric power system of the future - Integrating supergrids and microgrids International Symposium in Bologna, Italy 13-15 September, 2011

Non-Patent Document 2: Per Skarby, Ueli Steiger "An Ultra-fast Disconnecting Switch for a Hybrid HVDC Breaker - a technical breakthrough", Cigre, Canada conference, Calgary, Canada 9-11 September, 2013

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0008] A problem to be solved by the present invention is to provide a direct-current interrupter aimed to be small in size.

MEANS FOR SOLVING THE PROBLEMS

[0009] A direct-current interrupter of an embodiment includes: a current-carrying path; a commutation circuit; a semiconductor circuit breaker; and a non-linear resistor. The current-carrying path passes a direct current and includes first and second switches. The second switch is connected in series to the first switch and has a withstand voltage lower than a withstand voltage of the first switch. The semiconductor circuit breaker and the non-linear resistor are connected in parallel to the current-carrying path.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a view illustrating a configuration of a direct-current interrupter of a first embodiment.
Fig. 2 is a view illustrating a specific example of a commutation circuit of the direct-current interrupter in Fig. 1.
Fig. 3 is a sectional view illustrating a configuration of a vacuum valve of the direct-current interrupter.
Fig. 4 is a perspective view illustrating a configuration of a vertical magnetic field electrode portion of the vacuum valve in Fig. 3.
Fig. 5 is a chart illustrating a change in current in each circuit in the direct-current interrupter of the first embodiment.
Fig. 6 is a chart illustrating a difference in effect between presence and absence of a transient voltage suppression circuit in the first embodiment.
Fig. 7 is a view illustrating another configuration example of the transient voltage suppression circuit.
Fig. 8 is a view illustrating another configuration example of the transient voltage suppression circuit.
Fig. 9 is a view illustrating the other configuration example of the transient voltage suppression circuit.
Fig. 10 is a view illustrating a configuration of a direct-current interrupter of Modified Example 1.
Fig. 11 is a view illustrating a configuration of a direct-current interrupter of a second embodiment.
Fig. 12 is a chart illustrating a change in current in each circuit in the direct-current interrupter of the

second embodiment.

Fig. 13 is a view illustrating a configuration of a direct-current interrupter of Modified Example 2.

Fig. 14 is a view illustrating a configuration of a direct-current interrupter of a third embodiment.

Fig. 15 is a chart illustrating a change in current in each circuit in the direct-current interrupter of the third embodiment.

Fig. 16 is a view illustrating a configuration of a direct-current interrupter of Modified Example 3.

Fig. 17 is a view illustrating a configuration of a direct-current interrupter of a fourth embodiment.

Fig. 18 is a chart illustrating a change in current in each circuit in the direct-current interrupter of the fourth embodiment.

Fig. 19 is a view illustrating a configuration of a direct-current interrupter of Modified Example 4.

DETAILED DESCRIPTION

(First Embodiment)

[0011] Hereinafter, an embodiment will be explained in detail referring to the drawings. Fig. 1 illustrates a configuration of a direct-current interrupter of a first embodiment.

[0012] As illustrated in Fig. 1, the direct-current interrupter of the first embodiment has a current-carrying path 10, a current-interrupting path 30, a current detector 21, and a controller 50. The current-interrupting path 30 is connected in parallel to the current-carrying path 10. The current detector 21 detects a current through the whole of the current-carrying path 10 and the current-interrupting path 30. The controller 50 controls a flow of a current through the current-carrying path 10 and the current-interrupting path 30 based on a value of the current detected by the current detector 21.

[0013] The current-carrying path 10 has a switch 11 as a first switch, a switch 12 as a second switch, a resistor 13, a commutation circuit 14, and a transient voltage suppression circuit 15.

[0014] The switch 11 and the switch 12 are connected in series. The switch 11 has a first withstand voltage. The switch 11 is closing-controlled or opening-controlled by the controller 50, and switches between conduction and non-conduction of current without depending on a semiconductor circuit breaker 31 (irrelevantly to the semiconductor circuit breaker 31).

[0015] For the switch 11, a switch (gas switch) using an insulating gas such as SF_6 gas can be utilized. In this case, a vessel in which electrodes of the switch 11 are housed is filled with the insulating gas. By using the SF_6 gas or the like excellent in insulation performance, the withstand voltage of the switch 11 is improved, and its miniaturization is achieved.

[0016] The switch 12 has a second withstand voltage (for example, about several kV) lower than the first withstand voltage. The switch 12 is closing-controlled or opening-controlled by the controller 50, and switches between conduction and non-conduction of current without depending on the semiconductor circuit breaker 31 (irrelevantly to the semiconductor circuit breaker 31).

[0017] For the switch 12, a vacuum switch can be utilized, for example. A vacuum valve 120 (refer to Fig. 3 and Fig. 4 described later) can be utilized for a switch portion of the vacuum switch.

[0018] The commutation circuit 14 is connected in parallel to the switch 12. The commutation circuit 14 is a current source which outputs a current in a direction opposite to a direction of a current (a direct current flowing through the current-carrying path 10) to be interrupted. Note that these details are described later.

[0019] The transient voltage suppression circuit 15 is connected in parallel to the switch 12. The transient voltage suppression circuit 15 has, for example, a capacitor 15a and protects the switch 12 from a transient voltage to be applied to the switch 12.

[0020] Here, the transient voltage suppression circuit 15 is installed for only the switch 12. However, the transient voltage suppression circuit 15 may be installed for both the switches 11, and 12.

[0021] The current-interrupting path 30 has the semiconductor circuit breaker 31 as a semiconductor switch and a non-linear resistor 32 connected in parallel to this semiconductor circuit breaker 31.

[0022] The controller 50 starts opening control (interruption control) by which electrodes of the switches 11, 12 are operated to open when a value of a current detected by the current detector 21 exceeds a threshold value set in advance.

[0023] Further, the controller 50 controls the commutation circuit 14 and promotes switching (commutation) of a current path from the current-carrying path 10 to the semiconductor circuit breaker 31 after the start of the opening control (interruption control). Specifically, the controller 50 controls the commutation circuit 14 and injects a current in a direction opposite to a current direction of the switch 12 into the switch 12, thereby setting a current through the switch 12 (the current-carrying path 10) to "0" (zero). Consequently, the current flowing through the current-carrying path 10 flows through the semiconductor circuit breaker 31.

[0024] The controller 50 controls the semiconductor circuit breaker 31 in an on state and switches it to an off state after the start of the opening control of the electrodes of the switches 11, 12.

[0025] Hereinafter, an operation of this direct-current interrupter will be explained. In the direct-current interrupter at normal time, the switches 11, 12 of the current-carrying path 10 are closed, and current flows through the current-carrying path 10.

[0026] At current interruption time (when a current interruption is required due to an accident or the like), the semiconductor circuit breaker 31 is set in the on state, while the switches 11, 12 are interrupted. Moreover, a current in a direction opposite to a current flowing through the switch 12 is injected from the commutation circuit 14 into the switch 12, and the current flowing through the switch 12 (the current-carrying path 10) becomes "0" (zero). Consequently, a path of current switches immediately from the current-carrying path 10 to the current-interrupting path 30 (commutation). Thereafter, the current through the current-interrupting path 30 is decreased immediately, and the current is interrupted.

[0027] In Fig. 1, a direct current at normal time is generally considered to flow both from the left to the right and from the right to the left of the figure. This direct-current interrupter can deal with both of these.

[0028] Hereinafter, for easier understanding of the explanation, the direct current at normal time is set to flow from the left to the right of the figure.

[0029] The switches 11, 12 can switch between conduction and non-conduction of current without depending on the semiconductor circuit breaker 31. The switch 11 has a predetermined large withstand voltage property (described later). A withstand voltage property of the switch 12 is lower than the withstand voltage property of the switch 11. On the other hand, momentary interruption performance (high-speed property of opening and closing) of the switch 12 is higher than momentary interruption performance (high-speed property of opening and closing) of the switch 11. Note that details of the switch 12 will be explained in Fig. 3 and Fig. 4 described later.

[0030] The switches 11 and 12 are different in not only such properties (withstand voltage property and high-speed property) but also their roles. The switches 11 and 12 are connected in series and controlled by the controller 50, and the respective electrodes are opened and closed.

[0031] The resistor 13 is connected in parallel to the switch 12. Resistance of this resistor 13 is larger than on-resistance of the semiconductor circuit breaker 31 at current interruption time and smaller than resistance of the non-linear resistor 32 connected in parallel to the semiconductor circuit breaker 31.

[0032] The switch 11 in an open state is in an insulating state, and its resistance is sufficiently larger than the resistance of the resistor 13 connected in parallel to the switch 12. Therefore, when the switch 11 is in the open state, a large part of a voltage across the switches 11, 12 is applied to the switch 11. Consequently, a dielectric breakdown of the switch 12 is prevented.

[0033] The current detector 21 detects the current flowing through the whole of the current-carrying path 10 and the current-interrupting path 30 and communicates a value of the detected current to the controller 50. Therefore, the current detector 21 is disposed short of a position in which the current-carrying path 10 and the current-interrupting path 30 on a circuit through which current flows join.

[0034] As the current detector 21, for example, such configurations as the next (a) and (b) can be employed.

(a) A resistor having a very small resistance value is inserted into the current-carrying path 10. A voltage across this resistor is detected and converted into a current.

(b) A magnetic field generated from the current-carrying path 10 is detected by a Hall element or the like and converted into a current. In this case, the current flowing through the current-carrying path 10 can be detected in a non-contact manner.

[0035] The semiconductor circuit breaker 31 is the switch which is controlled by the controller 50 and switches between conduction and non-conduction of current. As a specific example of the semiconductor circuit breaker 31, as illustrated by the figure, here, a combination of an IGBT (Insulated Gate Bipolar Transistor) and a diode can be used. A pair of the IGBT and the diode is connected in inverse parallel (mutually inverse parallel in a forward direction). These two pairs are connected in series in opposite directions (face each other) and set as a unit element. A large number of the unit elements are connected in series and terminals are added to both ends thereof, thereby allowing the semiconductor circuit breaker 31 to be constituted.

[0036] When a voltage (caused by a control signal from the controller 50) is applied to both gates of two IGBTs in the unit element, the unit element becomes an on state (state in which current flows in either direction). By a combination of presence and absence of voltage application to two gates in the unit element, interruption of current, passage of current in the right direction, passage of current in the left direction, and passage (on state) of current in both the directions can be switched.

[0037] Various specific configurations of the semiconductor circuit breaker 31 can be employed other than the configuration in Fig. 2. The semiconductor circuit breaker 31 generally has resistance (on-resistance) in the on state, and a voltage drop is caused by conduction.

[0038] This voltage drop becomes large depending on the number of the above-described unit elements in series in a case of the semiconductor circuit breaker 31 illustrated in Fig. 1. That is, the on-resistance of the whole of the semiconductor circuit breaker 31 also becomes large depending on the number of these unit elements in series.

[0039] The number of the unit elements in series is determined so that the semiconductor circuit breaker 31 which is in an off state due to the current interruption can withstand high voltage to be applied thereto. The necessary number of the unit elements in series when a direct-current voltage is several hundreds of kV is generally a large number to some extent (for example, several hundreds).

[0040] The normal control of the semiconductor circuit breaker 31 by the controller 50 is as follows. The semiconductor circuit breaker 31 is set in an off state at normal time. At interruption time, the semiconductor circuit breaker 31 is switched to an on state once, thereafter immediately returning it to the off state.

[0041] However, the semiconductor circuit breaker 31 can also be controlled other than this normal method. For example, at normal time, the semiconductor circuit breaker 31 may be set in the on state. Also in this case, because of the on-resistance of the semiconductor circuit breaker 31, current hardly flows through the current-interrupting path 30, and the total current actually flows through the current-carrying path 10.

[0042] The commutation circuit 14 is connected in parallel to the switch 12. A current injection operation of the commutation circuit 14 is controlled by the controller 50. The commutation circuit 14 is controlled by the controller 50, thereby injecting a current (hereinafter, also referred to as "reverse current") in a direction opposite to a current to be interrupted into the switch 12.

[0043] For the commutation circuit 14, as illustrated in Fig. 2, a series circuit in which a capacitor 14a, a reactor 14b, and a semiconductor switch 14c are connected in series can be utilized.

[0044] The capacitor 14a is charged to a predetermined voltage by an unillustrated charging apparatus. In the semiconductor switch 14c, open (interruption) and closed (injection) states are controlled by the controller 50. The reactor 14b relaxes a flow of current at injection time. As in the later-described second embodiment and second modified example, it is possible to also omit the reactor 14b. Note that details of an operation of the commutation circuit 14 at current interruption time and a waveform of current at this time are described later.

[0045] When the current interruption is required due to an accident or the like, the controller 50 controls the commutation circuit 14 to forcibly cause current, which is injected into the switch 12. A direction of this current is opposite to a direction of a current (current to be interrupted) flowing through the switch 12. Consequently, the current flowing through the whole of the current-carrying path 10 becomes "0" (zero), and the path of current immediately switches from the current-carrying path 10 to the current-interrupting path 30 (semiconductor circuit breaker 31) (commutation).

[0046] That is, using the commutation circuit 14 makes it possible to achieve commutation from the current-carrying path 10 to the semiconductor circuit breaker 31 while a current at accident time is still small. This makes it possible to suppress a current flowing through the semiconductor circuit breaker 31 and avoid an increase in its allowable current (easy miniaturization of the semiconductor circuit breaker 31).

[0047] The non-linear resistor 32 is connected in parallel to the semiconductor circuit breaker 31. The non-linear resistor 32 functions at a final stage of the interruption operation of this direct-current interrupter. Specifically, when both the current-carrying path 10 and the semiconductor circuit breaker 31 do not pass current, the non-linear resistor 32 temporarily passes current.

[0048] At an initial stage at which current temporarily flows through the non-linear resistor 32, a current with the same value as that of a current which has flowed through the semiconductor circuit breaker 31 immediately before the stage flows. Because a relatively large voltage drop is caused in the non-linear resistor 32 by this current, the current decreases. When the current decreases, a resistance value is increased by nonlinearity of resistance. Due to the increased resistance value, the current reaches substantially zero, and the interruption of the current is completed.

[0049] Note that the current detected by the current detector 21 is communicated to the controller 50. Then, the controller 50 controls opening and closing of the electrodes of the switches 11, 12, and on/off switching of the semiconductor circuit breaker 31. Further, the controller 50 controls on/off of the commutation circuit 14 which is a source of a reverse current, and an output current thereof.

[0050] There is each subordinate controller corresponding to each of these controls inside the controller 50. These subordinate controllers are connected to one another, and information necessary for the controls is communicated and shared.

[0051] When the transient voltage suppression circuit 15 is not installed, a steep voltage occurs in the switches 11, 12 as soon as a current through the switch 12 is set to "0" (zero). However, installing the transient voltage suppression circuit 15 makes it possible to suppress a transient voltage which occurs as soon as the current is set to "0" (zero) (near a time E in Fig. 3).

[0052] Here, a specific example (hardware configuration) of the switch 12 of the direct-current interrupter will be explained referring to Fig. 3 and Fig. 4.

[0053] Fig. 3 illustrates a hardware configuration of the vacuum valve 120 which is a switch portion of the switch 12 of the direct-current interrupter. Fig. 4 illustrates a configuration of a vertical magnetic field electrode portion of the vacuum valve 120 in Fig. 3.

[0054] For the switch 12, the vacuum valve (vacuum switch) 120 which is one kind of switch is used.

[0055] As illustrated in Fig. 3, the vacuum valve 120 has a cylindrical insulating tube 121, a fixed side electrode 122, a movable side electrode 123, a fixed side current-carrying shaft 124, a movable side current-carrying shaft 125, and a bellows 126 as main components.

[0056] Here, a main configuration of the vacuum valve 120 is exemplified. Other than this, the vacuum valve 120 is also provided with a drive mechanism (not illustrated) for moving the movable side current-carrying shaft 125 in its axial direction.

[0057] The cylindrical insulating tube 121 is a tube-shaped vessel whose opening portions of both ends are sealed. This vessel is a vacuum vessel whose inside is maintained almost under vacuum.

[0058] The bellows 126 is disposed in a sliding portion between the insulating tube 121 and the movable side current-carrying shaft 125. The bellows 126 makes it possible to drive the movable side current-carrying shaft 125 in an arrow direction while maintaining a vacuum state in this vacuum vessel (while interrupting from the outside).

[0059] In general, the vacuum switch does not have a very high withstand voltage property but is excellent in a dielectric recovery characteristic. Therefore, the vacuum switch can be used suitably as the switch 12. After the current through the current-carrying path 10 becomes "0" (zero), a relatively low voltage due to the voltage drop of the semiconductor circuit breaker 31 in the on state is applied to the switch 12. The vacuum switch withstands this low applied voltage and has an excellent dielectric recovery characteristic as the direct-current interrupter.

[0060] The fixed side electrode 122 and the movable side electrode 123 of this vacuum valve 120 constitute a vertical magnetic field electrode.

[0061] As illustrated in Fig. 4, on a peripheral edge portion (outer peripheral surface) of each of the fixed side electrode 122 and the movable side electrode 123, slits 127, 128 are each disposed in an oblique direction so as to depict a spiral with respect to the center axis. Because this spiral direction (here, right-hand screw direction) is the same in the fixed side electrode 122 and the movable side electrode 123, currents 129, 130 rotate in the same direction. Consequently, a vertical magnetic field 132 is applied to an arc 131 in the vacuum valve 120 by the rotating currents 129, 130.

[0062] By driving the movable side current-carrying shaft 125 of the switch 12 during conduction and opening the movable side electrode 123 and the fixed side electrode 122 (also referred to as opening control or interruption control), the arc 131 is caused between the fixed side electrode 122 and the movable side electrode 123.

[0063] At this time, the vertical magnetic field 132 is generated by the currents 129, 130 caused by the arc 131. The vertical magnetic field 132 stabilizes the arc 131, which is distributed uniformly over the whole of the electrodes. Consequently, partial damage to the electrodes due to the arc 131 is suppressed. Thus, suppressing the damage to the electrodes makes it possible to maintain the excellent dielectric recovery characteristic.

[0064] Next, a time-series operation of the direct-current interrupter of the first embodiment will be explained referring to Fig. 5. Fig. 5 illustrates a time-series change in current in each of parts of the direct-current interrupter.

[0065] Fig. 5 illustrates a time-series change in each of a total current 41 which is the sum current of the current flowing through the current-carrying path 10 and the current flowing through the current-interrupting path 30, a current 42 through the semiconductor circuit breaker 31, a current 43 through the switch 12, an applied voltage 45 to the direct-current interrupter.

[0066] At an initial stage before a time A at which an accident occurs, a current at normal time flows.

[0067] At this time, the current flows through only the switch 12 (only the current-carrying path 10). That is, at this stage, the current 42 does not flow through the semiconductor circuit breaker 31 (current-interrupting path 30).

[0068] At the time A, an accident is set to occur in a direct-current power transmission system. At and after the time A, the total current 41 increases. Then, when a value of the current (current flowing through the current-carrying path 10) detected by the current detector 21 exceeds a set threshold value, the controller 50 decides to be an abnormality (detection of occurrence of an accident, time B).

[0069] When the accident is detected, the controller 50 starts the interruption control (electrode opening control) for operating the respective electrodes to open them (interruption operation) with respect to the switches 11, 12 (time C).

[0070] When the interruption control (electrode opening control) of the switches 11, 12 is started, a pair of the electrodes of each of these switches 11, 12 is physically separated, but an arc is generated between a pair of the electrodes at the beginning of the separation and the current continues flowing.

[0071] After the start of the interruption control (electrode opening control), the controller 50 controls the commutation circuit 14, and a reverse current is injected from the commutation circuit 14 into the switch 12 (time D). When the reverse current is injected into the switch 12, the current 43 through the switch 12 decreases and reaches "0" (zero) (time E). With this, the commutation of the current flowing through the current-carrying path 10 to the current-interrupting path 30 is completed.

[0072] From the times E to F, the current flows through only the semiconductor circuit breaker 31. At this time, the current 42 flowing through the semiconductor circuit breaker 31 and the on-resistance thereof cause a certain level of voltage drop 44. At this time, this voltage drop 44 (for example, several kV) can be the applied voltage 45 to the direct-current interrupter (a voltage (voltage drop 44) across the semiconductor circuit breaker 31 is applied almost as it is to the switch 12). This is because there is a possibility that an open state of the electrodes of the switch 11 is not established.

[0073] The switch 12 has the withstand voltage of, as described above, for example, about several kV so as to withstand this voltage drop 44.

[0074] After the time E, at and after the time point (time F) at which the open state of the electrodes of the switches 11, 12 is (considered) to have been established, the controller 50 controls the semiconductor circuit breaker 31, which is set to off (a state in which a flow of current is interrupted).

[0075] At a time point of the time E, the current through the current-carrying path 10 has already been set to be in non-conduction, and at the time F, the semiconductor circuit breaker 31 is switched to a state of non-conduction of current by off control. Therefore, at and after the time F, current temporarily flows through the non-linear resistor 32.

[0076] At an initial stage at which the current temporarily flows through the non-linear resistor 32, the current with the same value as that of the current which has flowed through the semiconductor circuit breaker 31 immediately before the stage flows. This causes a relatively large voltage drop (for example, 500 kV) in the non-linear resistor 32, and the current decreases.

[0077] When the current decreases, a resistance value is increased by the nonlinearity of the resistance of the non-linear resistor 32. Due to the increased resistance value, the total current 41 reaches substantially zero, and the current interruption is completed (time G).

[0078] At and after the time G, a state in which a direct-current voltage 44 (for example, 300 kV) according to this direct-current power transmission system is applied to this direct-current interrupter is brought.

[0079] By operating the direct-current interrupter at such normal timing as illustrated in Fig. 5, in the switch 11 or 12, the current caused by the arc flows between the electrodes after the opening control of the electrodes thereof, and the electrical resistance increases. Consequently, the current can be more quickly commuted from the current-carrying path 10 to the current-interrupting path 30. That is, the operation of the direct-current interrupter becomes faster.

[0080] Here, an effect of the transient voltage suppression circuit 15 will be explained referring to Fig. 6.

[0081] As illustrated in Fig. 6, when the transient voltage suppression circuit 15 is not installed (a case of absence of the transient voltage suppression circuit 15), a high transient voltage 51 suddenly occurs when the commutation is completed (time E). However, when the transient voltage suppression circuit 15 is installed, a transient voltage is absorbed by a capacitor 15a, and a transient voltage 52 decreases.

[0082] Thus, in the direct-current interrupter of this first embodiment, since the switch (semiconductor circuit breaker 31) using a semiconductor is not used for the current-carrying path 10, a power loss at current-carrying time can be greatly decreased. Further, since the commutation circuit 14 is disposed in parallel to the switch 12, the current through the current-carrying path 10 can be forcibly commuted quickly (as one example, at about several ms) to the current-interrupting path 30.

[0083] Accordingly, it becomes possible to decrease a value of the current to be interrupted in the current-interrupting path 30, and an increase in a size of the interrupter can be avoided. More specifically, reducing current rating of the semiconductor circuit breaker 31 makes it possible to avoid the increase in the size.

[0084] That is, even when a value of a direct current passing through the current-carrying path 10 is large, it is possible to have a small size and reduce a current-carrying loss at normal time.

[0085] In the first embodiment, the capacitor 15a is used for the transient voltage suppression circuit 15, but other than this, for example, such circuits as illustrated in Fig. 7 to Fig. 9 can be employed. Fig. 7 illustrates a series circuit of the capacitor 15a and a reactor 15b. Fig. 8 illustrates a series circuit of the capacitor 15a and a resistor 15c. Fig. 9 illustrates a series circuit of the capacitor 15a, the reactor 15b, and the resistor 15c.

[0086] As illustrated in these examples, the transient voltage suppression circuit 15 can be the series circuit of the capacitor 15a and a reactor 15b, the series circuit of the capacitor 15a and the resistor 15c, or the series circuit of the capacitor 15a, the reactor 15b, and the resistor 15c. Consequently, not only the current flowing between the electrodes of the switch 12 but also the damage to the electrodes due to discharge can be suppressed by the reactor 15b or the resistor 15c.

[0087] In a case of these examples, in a process of changing the switch 12 from the open state to the closed state, when an interelectrode distance of the switch 12 becomes small, an electric charge stored in the capacitor 15a of the transient voltage suppression circuit 15 is discharged, and the current flows between the electrodes of the switch 12. Therefore, a voltage suppression effect at the time E at current interruption time is the same as that in a case of using the capacitor 15a alone.

[0088] Further, in the above-described first embodiment, a resistor having a fixed resistance value is used as the resistor 13, but, for example, a non-linear resistor may be used other than this. As the non-linear resistor, for example, a lightning arrester element can be utilized.

[0089] It is preferable that a voltage of the non-linear resistor to be used as the resistor 13 is higher than a voltage due to the on-resistance of the semiconductor circuit breaker 31 and lower than that of the non-linear resistor 32 connected in parallel to the semiconductor circuit breaker 31. The resistance of the non-linear resistor to be used as this resistor 13 preferably decreases at a voltage lower than a limit of the withstand voltage of the switch 12.

[0090] When a voltage higher than the withstand voltage is applied to the switch 12, a resistance value of the non-linear resistor used as the resistor 13 decreases. As a result, the voltage to be applied to the switch 12 is reduced, which allows prevention of dielectric breakdown in the switch 12.

(Modified Example 1)

[0091] Fig. 10 illustrates a configuration of a direct-current interrupter of Modified Example 1. In the direct-current interrupter of Modified Example 1, the transient voltage suppression circuit 15 is eliminated from the direct-current interrupter of the first embodiment. Thus, even without having the transient voltage suppression circuit 15, the direct-current interrupter is capable of operating as a direct-current interrupter. Because this operation can be represented by Fig. 5 similarly to that of the direct-current interrupter of the first embodiment, an explanation thereof is omitted.

(Second Embodiment)

[0092] Next, a current interrupter of a second embodiment will be explained referring to Fig. 11. This second embodiment is an example in which a circuit near the switch 12 of the direct-current interrupter of the first embodiment illustrated in Fig. 1 is modified, and the same components as those of the first embodiment are denoted by the same reference signs and an explanation thereof is omitted.

[0093] In this second embodiment, a saturable reactor 16 is connected in series to the switch 12. A commutation circuit 14 is constituted by a series circuit of a capacitor 14a and a semiconductor switch 14c.

[0094] That is, in this second embodiment, a series circuit of the switch 12 and the saturable reactor 16, the commutation circuit 14 in which the capacitor and the semiconductor switch are connected in series, and a resistor 13 are connected in parallel.

[0095] In this example, the commutation circuit 14 does not have a reactor 14b but may have the reactor 14b as illustrated in Fig. 2.

[0096] In this second embodiment, the commutation circuit 14, the saturable reactor 16, and the switch 12 constitute a closed circuit. The saturable reactor 16 has changing points of a saturated state and a non-saturated state in a value of current equal to or less than the current which is to be interrupted in the switch 12. This current value is the degree of a direct current at a normal state.

[0097] Hereinafter, different portions in changes in current from those in the first embodiment in an operation at current interruption time of the direct-current interrupter of this second embodiment will be explained referring to Fig. 12.

[0098] A controller 50 controls the commutation circuit 14 and makes the commutation circuit 14 inject a reverse current into the switch 12 at the time point of the time D after the opening control (interruption) of the switch 12 at the time C.

[0099] With this, a current with the same value as that of the switch 12 flows through the saturable reactor 16. When this current decreases and the saturable reactor 16 changes from the saturated state to the non-saturated state, an inductance of the saturable reactor 16 increases. As a result, in the time-series change in a current 42 flowing through a semiconductor circuit breaker 31 illustrated in Fig. 12, from the times D to E, for example, at a time 62, the change in the current becomes gradual. Therefore, the change in a current 43 flowing through the switch 12 becomes gradual at a time 63 immediately before a current zero point.

[0100] Thus, according to this second embodiment, an effect similar to that in the first embodiment can be obtained, at the same time the current can be securely commuted to a current-interrupting path 30 at the current zero point. This is because owing to the saturable reactor 15 connected in series to the switch 12, a rate of change in the current flowing through the switch 12 at current interruption time becomes gradual immediately before the current zero point, thereby causing a period in a small current state.

(Modified Example 2)

[0101] Fig. 13 illustrates a configuration of a direct-current interrupter of Modified Example 2. In the direct-current interrupter of Modified Example 2, a transient voltage suppression circuit 15 is eliminated from the direct-current interrupter of the second embodiment. Thus, even without having the transient voltage suppression circuit 15, the direct-current interrupter is capable of operating as a direct-current interrupter. Because this operation can be represented by Fig. 12 similarly to that of the direct-current interrupter of the second embodiment, an explanation thereof is omitted.

(Third Embodiment)

[0102] Next, a current interrupter of a third embodiment will be explained referring to Fig. 14 and Fig. 15. This third embodiment is a modified example of the direct-current interrupter of the first embodiment illustrated in Fig. 1, and the same components as those of the first embodiment are denoted by the same reference signs and an explanation thereof is omitted.

[0103] As illustrated in Fig. 14, in this third embodiment, an interelectrode distance detector 22 is installed on the switch 12 of the first embodiment. The interelectrode distance detector 22 detects an interelectrode distance of the switch 12 and notifies it to a controller 50. The controller 50 controls the switch 12 and a commutation circuit 14 based on the interelectrode distance of the switch 12 notified from the interelectrode distance detector 22.

[0104] In a case of this third embodiment, as illustrated in Fig. 15, the switch 12 is controlled in consideration of a time C1. The time C1 is a time at which an electrode distance of the switch 12 reaches a predetermined distance and is predicted from the time C of the start of the electrode opening control to the switch 12.

[0105] The controller 50 determines a timing at which a semiconductor switch 14c of the commutation circuit 14 is turned on and controls the commutation circuit 14 so that the commutation from a current-carrying path 10 to a current-interrupting path 30 is completed at a time point later than this time C1 (commutation completion is at the time E).

[0106] That is, in this third embodiment, the interelectrode distance of the switch 12 detected by the interelectrode distance detector 22 is continuously communicated to the controller 50. The controller 50 prediction calculates the time C1 at which the electrode distance of the switch 12 detected by the interelectrode distance detector 22 reaches the predetermined distance (threshold value). The controller 50 controls electrode opening of the switch 12 at a start timing (time C) of the electrode opening control to the switch 12 before the time C1. An operation thereafter is the same as that in the first embodiment.

[0107] Thus, according to this third embodiment, the interelectrode distance detector 22 is installed on the switch 12, and control timing of the switch 12 is acquired. Therefore, from becoming a state in which the withstand voltage property of the switch 12 is secured sufficiently, voltage application to the switch 12 corresponding to the voltage drop caused by a semiconductor circuit breaker 31 occurs (a period therefor is at and after the time E to the time F). Consequently, in the operation of the switch 12, a very desirable result can be obtained.

[0108] Note that in the third embodiment, the interelectrode distance detector 22 is installed on the switch 12, and the interelectrode distance of the switch 12 is detected to perform the interruption control. However, the time at which the distance between the electrodes reaches the predetermined distance is detected in advance. Therefore, without installing the interelectrode distance detector 22, the time C1 at which the electrode distance of the switch 12 reaches the predetermined distance is predicted from the time C of the start of the electrode opening control to the switch 12, and control according to elapsed time after the interruption operation start is also allowable.

(Modified Example 3)

[0109] Fig. 16 illustrates a configuration of a direct-current interrupter of Modified Example 3. In the direct-current interrupter of Modified Example 3, a transient voltage suppression circuit 15 is eliminated from the direct-current interrupter of the third embodiment. Thus, even without having the transient voltage suppression circuit 15, the direct-current interrupter is capable of operating as a direct-current interrupter. Because this operation can be represented by Fig. 15 similarly to that of the direct-current interrupter of the second embodiment, an explanation thereof is omitted.

(Fourth Embodiment)

[0110] Next, a current interrupter of a fourth embodiment will be explained referring to Fig. 17 and Fig. 18. This fourth embodiment is a modified example of the direct-current interrupters of the first and third embodiments illustrated in Fig. 1 and Fig. 14, and the same components as those of the first and third embodiments are denoted by the same reference signs and an explanation thereof is omitted.

[0111] As illustrated in Fig. 17, in this fourth embodiment, an interelectrode distance detector 23 is increased on the switch 11 of the first embodiment. The interelectrode distance detector 23 detects an interelectrode distance of the switch 11 and notifies it to a controller 50. The controller 50 controls the switch 11 and a semiconductor circuit breaker 31 based on the interelectrode distance of the switch 11 notified from the interelectrode distance detector 23 or elapsed time after the electrode opening control.

[0112] In a case of this fourth embodiment, as illustrated in Fig. 18, control of a switch 12 is performed in consideration of a time C2. The time C2 is a time which is predicted from the time C of the start of the electrode opening control to the switch 11 and at which an electrode distance of the switch 11 reaches a predetermined distance. The controller 50 controls the semiconductor circuit breaker 31 in the on state at a time point (for example, time F) later than this time C2 so as to switch to off (state of switching off current).

[0113] That is, in this fourth embodiment, the interelectrode distance of the switch 11 detected by the interelectrode distance detector 22 is constantly communicated to the controller 50. The controller 50 prediction calculates the time C2 at which the electrode distance of the switch 11 detected by the interelectrode distance detector 23 reaches the predetermined distance (threshold value) set in advance. The controller 50 determines a start timing (time C) of the electrode opening control to the switch 11 before the time C2 and performs the interruption control of the switch 11 and the semiconductor circuit breaker 31. An operation thereafter is the same as those in Modified examples 1, 3.

[0114] Thus, according to this fourth embodiment, the interelectrode distance detector 23 is disposed on the switch 11, and control timing of the switch 11 is acquired. Therefore, from becoming a state in which the withstand voltage property of the switch 11 is secured sufficiently, a high applied voltage to the direct-current interrupter occurs (a period therefor is at and after the time F). Consequently, in the operation of the switch 11, a very desirable result can be obtained.

[0115] Note that in the fourth embodiment, the interelectrode distance detector 23 is disposed on the switch 11, and the interelectrode distance of the switch 11 is detected to perform the interruption control. However, the time at which the distance between the electrodes reaches the predetermined distance is detected in advance. Therefore, without disposing the interelectrode distance detector 23, the time C2 until the electrode distance of the switch 11 reaches the predetermined distance is predicted from the time C of the start of the electrode opening control to the switch 11, and control according to elapsed time after the interruption operation start (after the start of the electrode opening control of the switch 11) is also allowable.

(Modified Example 4)

[0116] Fig. 19 illustrates a configuration of a direct-current interrupter of Modified Example 4. In the direct-current interrupter of Modified Example 4, a transient voltage suppression circuit 15 is eliminated from the direct-current interrupter of the fourth embodiment. Thus, even without having the transient voltage suppression circuit 15, the direct-current interrupter is capable of operating as a direct-current interrupter. Because this operation can be represented by Fig. 18 similarly to that of the direct-current interrupter of the second embodiment, an explanation thereof is omitted.

[0117] According to at least one of the embodiments and the modified examples explained above, it is possible to reduce a current-carrying loss at normal time and avoid an increase in size of a device configuration. In other words, it is possible to provide a direct-current interrupter which has a small size and allows the current-carrying loss at normal time to be reduced even when a current which is to be interrupted is large.

[0118] While certain embodiments of the present invention have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

Claims

1. A direct-current interrupter comprising:

a current-carrying path for passing a direct current, comprising

a first switch, and
a second switch connected in series to the first switch and having a withstand voltage lower than a withstand voltage of the first switch;

a commutation circuit connected in parallel to the second switch and configured to inject a current in a direction opposite to a direction of the direct current into the second switch;
a semiconductor circuit breaker connected in parallel to the current-carrying path; and
a non-linear resistor connected in parallel to the current-carrying path.

2. The direct-current interrupter according to claim 1, wherein the commutation circuit comprises a capacitor and a switch connected in series to each other.

3. The direct-current interrupter according to claim 2, wherein the commutation circuit further comprises a reactor connected in series to the capacitor and the switch.

4. The direct-current interrupter claim 1, further comprising a voltage suppression circuit connected in parallel to the second switch and including a second capacitor.

5. The direct-current interrupter according to claim 4, wherein the voltage suppression circuit further comprises:

a second reactor connected in series to the second capacitor;
a second resistor connected in series to the second capacitor; or
a second reactor and a second resistor connected in series to the second capacitor.

6. The direct-current interrupter according to claim 1, further comprising a third resistor connected in parallel to the second switch.

7. The direct-current interrupter according to claim 6, wherein the third resistor is a non-linear resistor.

8. The direct-current interrupter according to claim 1, further comprising a saturable reactor connected in series to the first and second switches,
wherein the second switch and the saturable reactor connected in the series are connected in parallel to the commutation circuit.

9. The direct-current interrupter according to claim 1, wherein the second switch is a vacuum switch.

10. The direct-current interrupter according to claim 9, wherein the second switch is a vacuum switch having a vertical magnetic field electrode.

11. The direct-current interrupter according to claim 1, wherein the first switch is a gas switch.

12. The direct-current interrupter according to claim 1, further comprising a controller configured to:

start interruption control to interrupt the first and second switches when an abnormality is detected in the direct current flowing through the current-carrying path,
switch a path of the direct current from the current-carrying path to the semiconductor circuit breaker by controlling the commutation circuit and injecting the current in an opposite direction into the second switch after the start of the interruption control, and
control the semiconductor circuit breaker and switches from on to off after the switching.

13. The direct-current interrupter according to claim 12, wherein the controller starts control of the commutation circuit after a predetermined time from when the second switch becomes open.

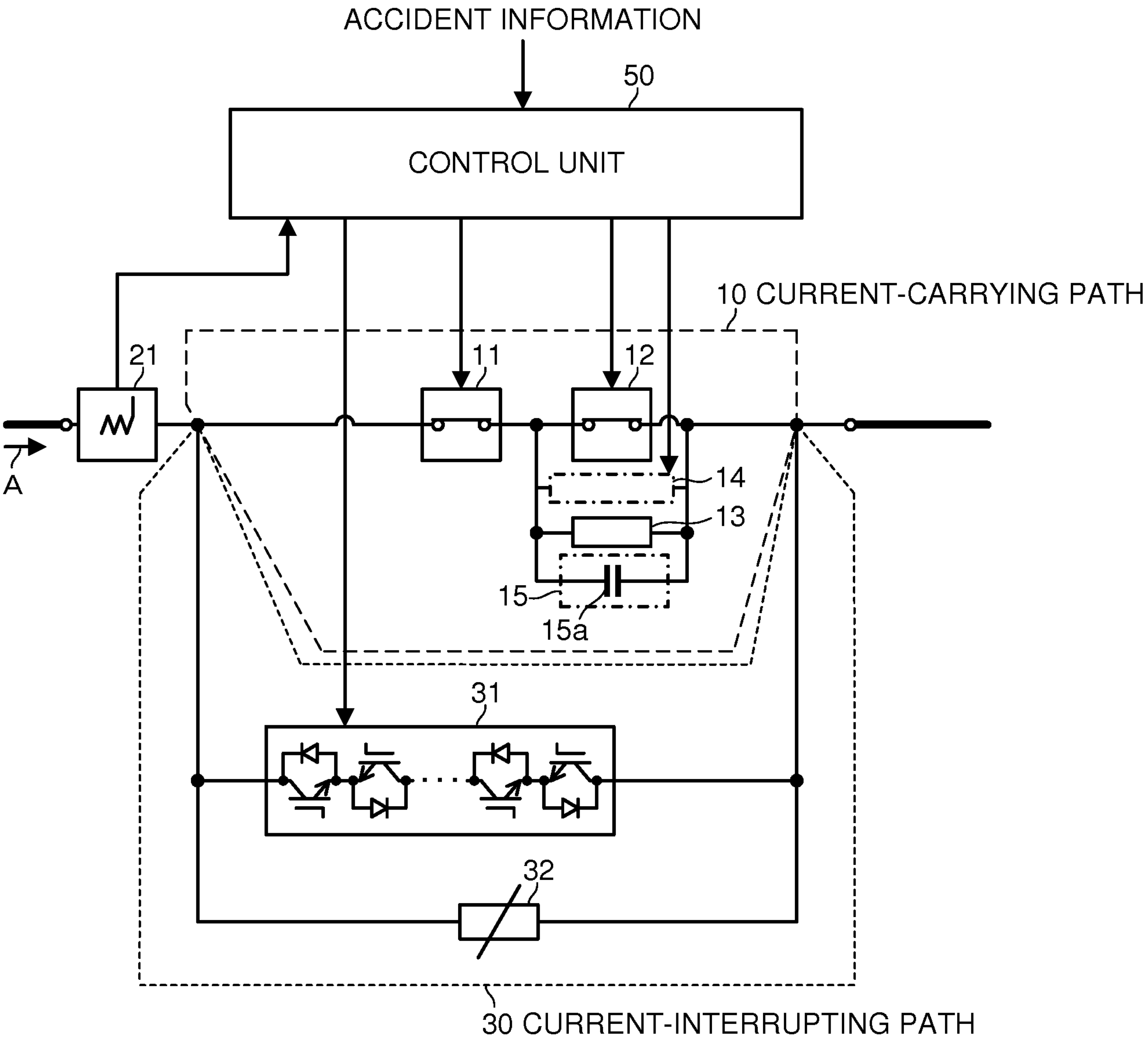
14. The direct-current interrupter according to claim 12, further comprising a detector configured to detects an interelectrode distance of the second switch, wherein the controller starts control of the commutation circuit based on the detected interelectrode distance.

15. The direct-current interrupter according to claim 12, wherein the controller controls the semiconductor circuit breaker and switches from on to off after a predetermined time from when the first switch becomes open.

16. The direct-current interrupter according to claim 12, further comprising a detector configured to detect an interelectrode distance of the first switch, wherein the controller switches the semiconductor circuit breaker from on to off based on the detected interelectrode distance.

17. The direct-current interrupter according to claim 16, wherein the controller switches the semiconductor circuit breaker from on to off when the interelectrode distance reaches a predetermined distance after the commutation circuit injects the current in an opposite direction into the second switch.

FIG. 1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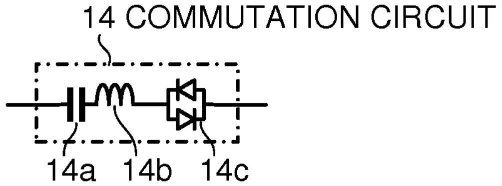
30 CURRENT-INTERRUPTING PATH

FIG. 2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14a
14b
14c

FIG. 3

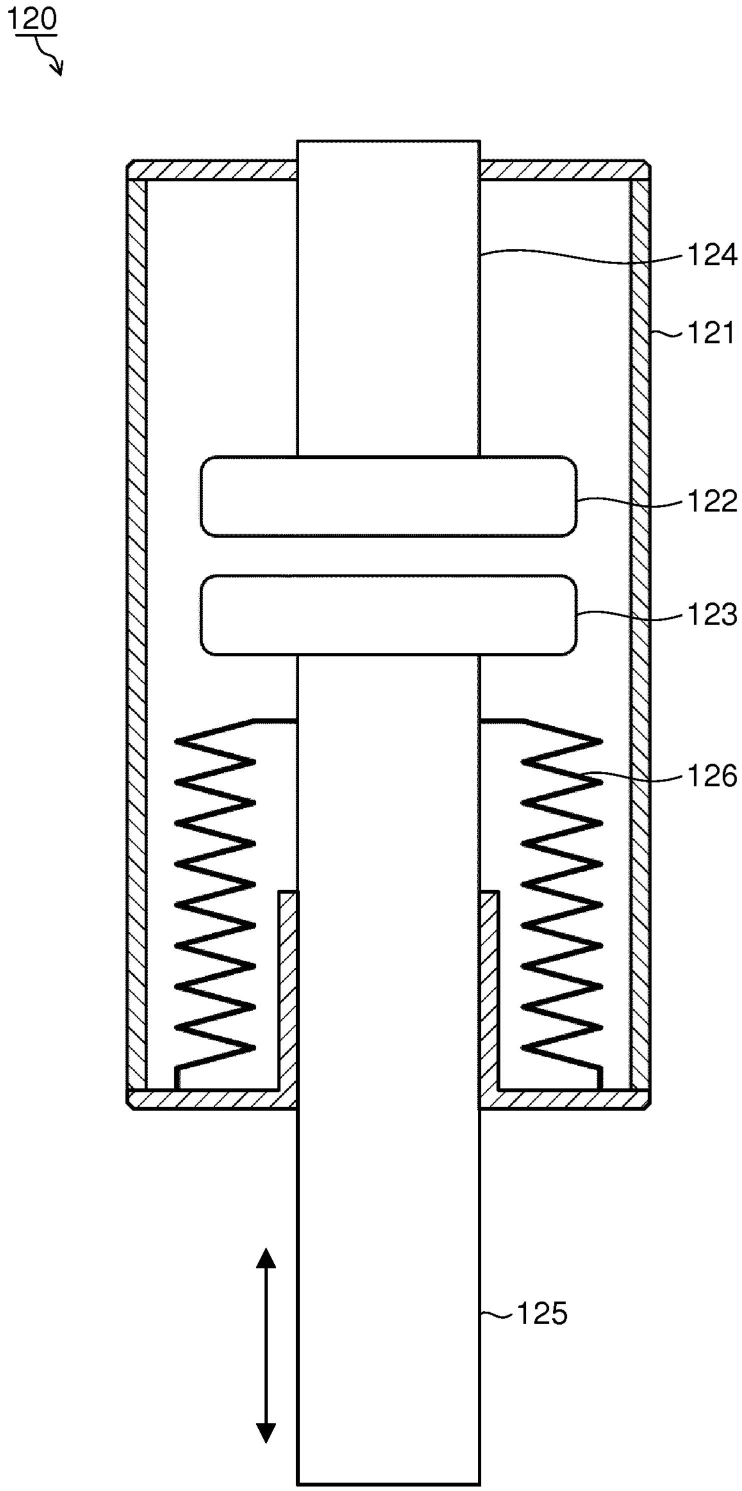


FIG. 4

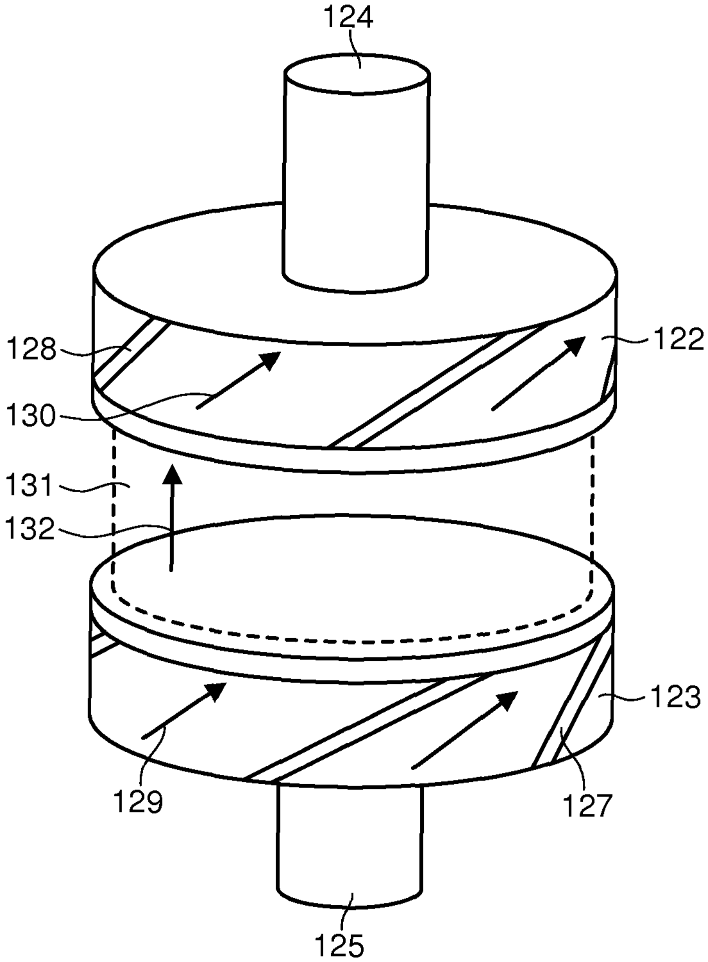
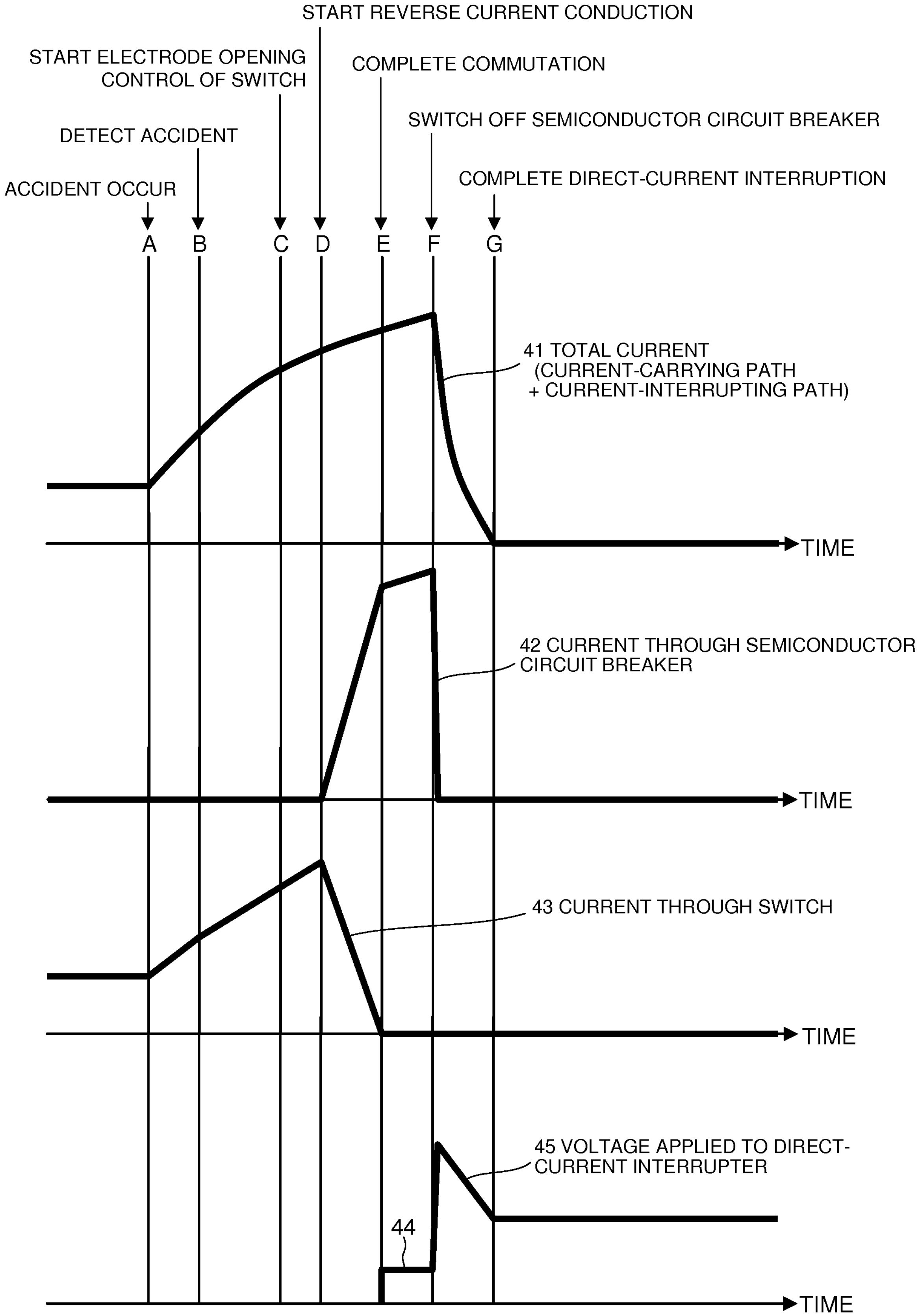


FIG. 5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SWITCH OFF SEMICONDUCTOR CIRCUIT BREAKER
DETECT ACCIDENT
COMPLETE DIRECT-CURRENT INTERRUPTION
ACCIDENT OCCUR
A
B
C
D
E
F
G
41 TOTAL CURRENT (CURRENT-CARRYING PATH + CURRENT-INTERRUPTING PATH)
TIME
42 CURRENT THROUGH SEMICONDUCTOR CIRCUIT BREAKER
TIME
43 CURRENT THROUGH SWITCH
TIME
45 VOLTAGE APPLIED TO DIRECT-CURRENT INTERRUPTER
44
TIME

FIG. 6

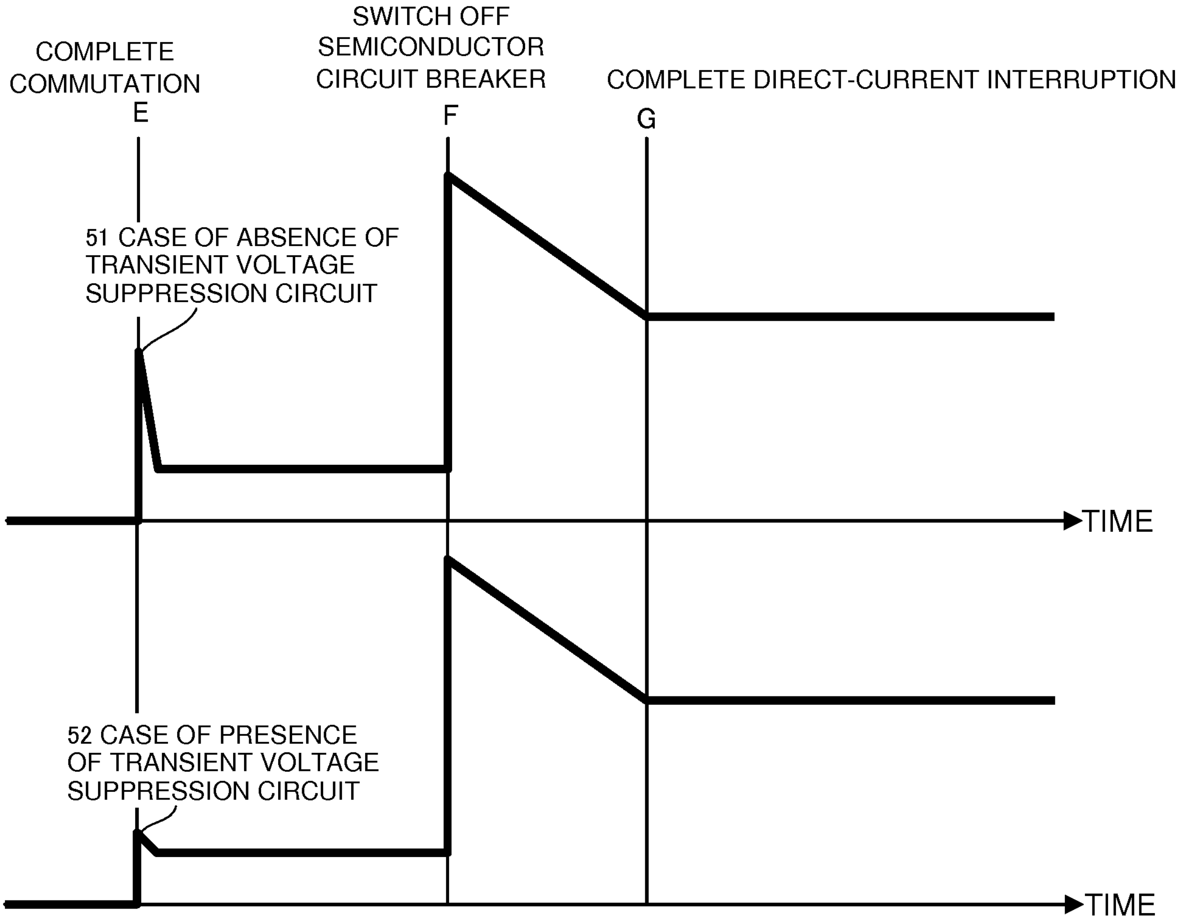


FIG. 7

FIG. 8

FIG. 9

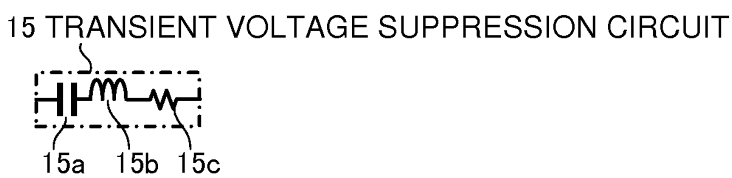
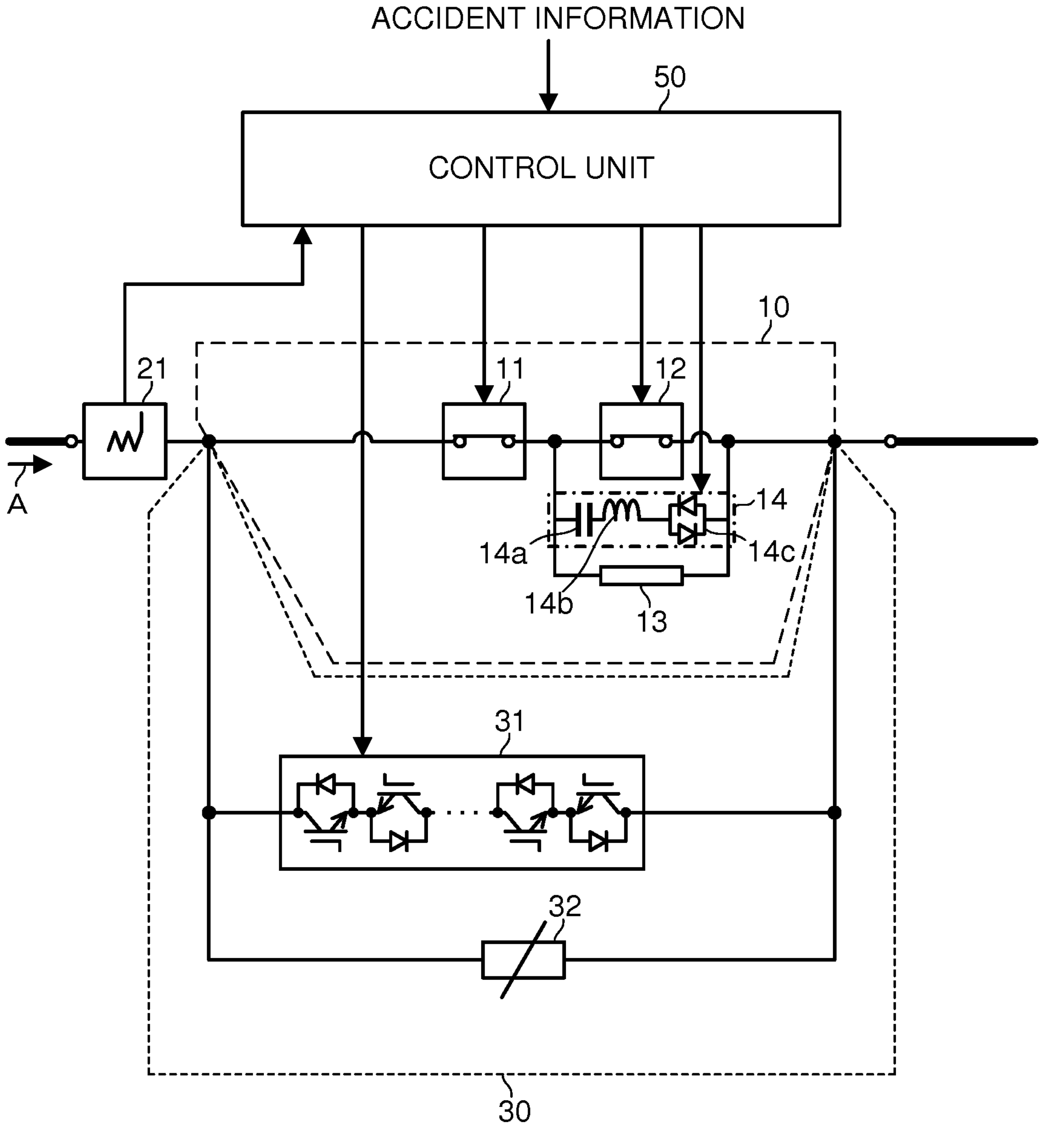


FIG. 10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14c
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FIG. 11

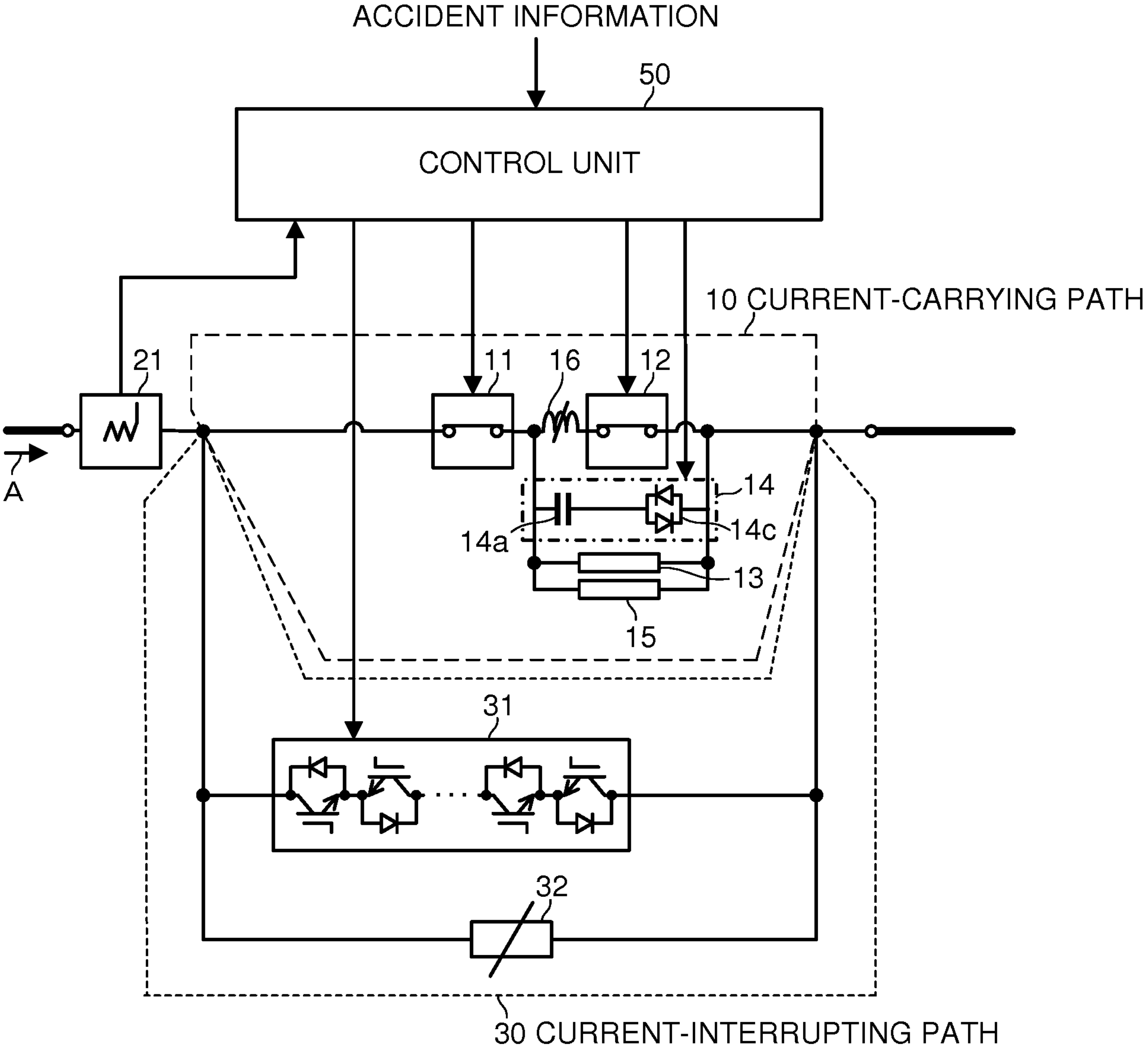
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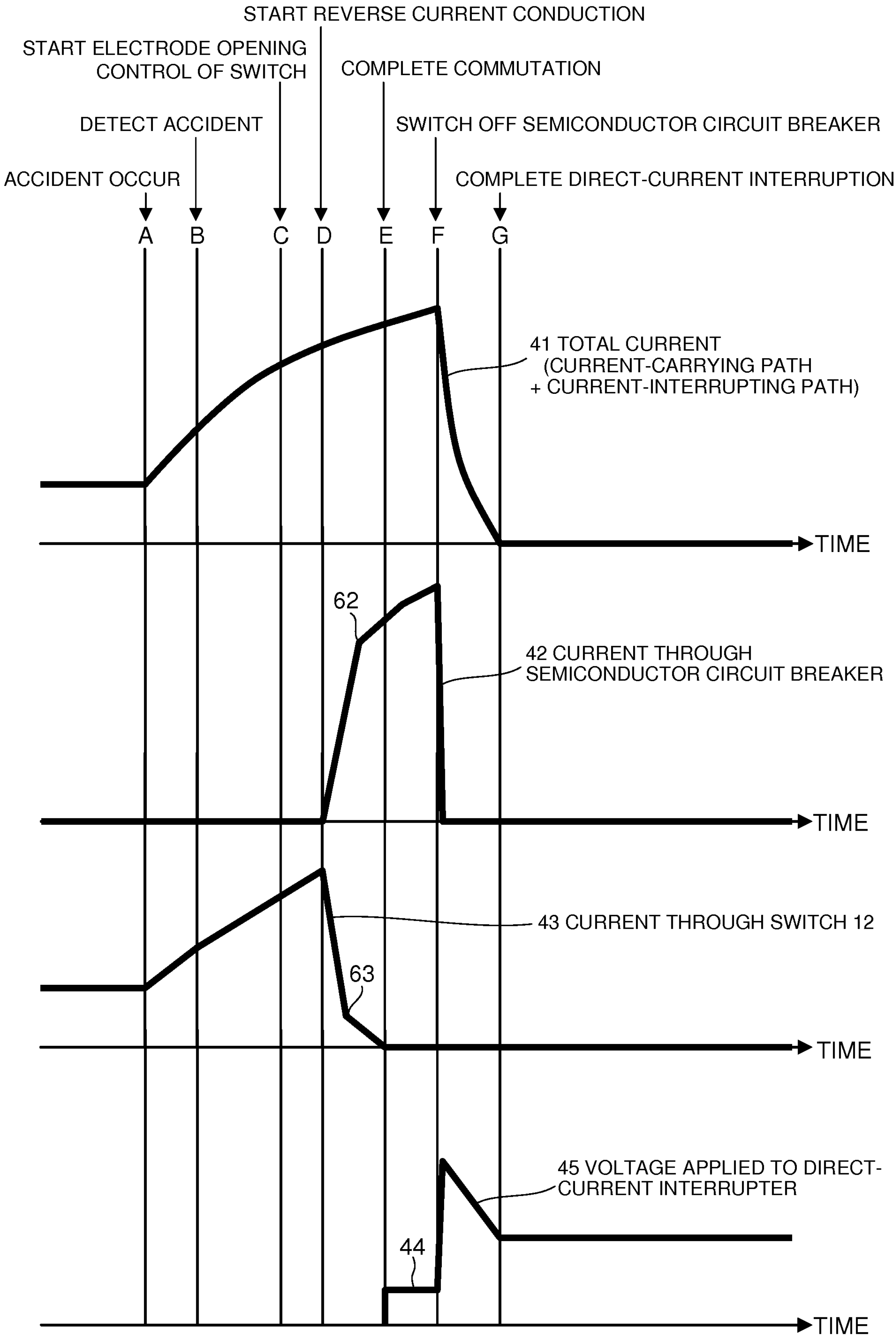
FIG. 12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COMPLETE COMMUTATION
DETECT ACCIDENT
SWITCH OFF SEMICONDUCTOR CIRCUIT BREAKER
ACCIDENT OCCUR
COMPLETE DIRECT-CURRENT INTERRUPTION
A
B
C
D
E
F
G
41 TOTAL CURRENT (CURRENT-CARRYING PATH + CURRENT-INTERRUPTING PATH)
TIME
62
42 CURRENT THROUGH SEMICONDUCTOR CIRCUIT BREAKER
TIME
43 CURRENT THROUGH SWITCH 12
63
TIME
45 VOLTAGE APPLIED TO DIRECT-CURRENT INTERRUPTER
44
TIME

FIG. 13

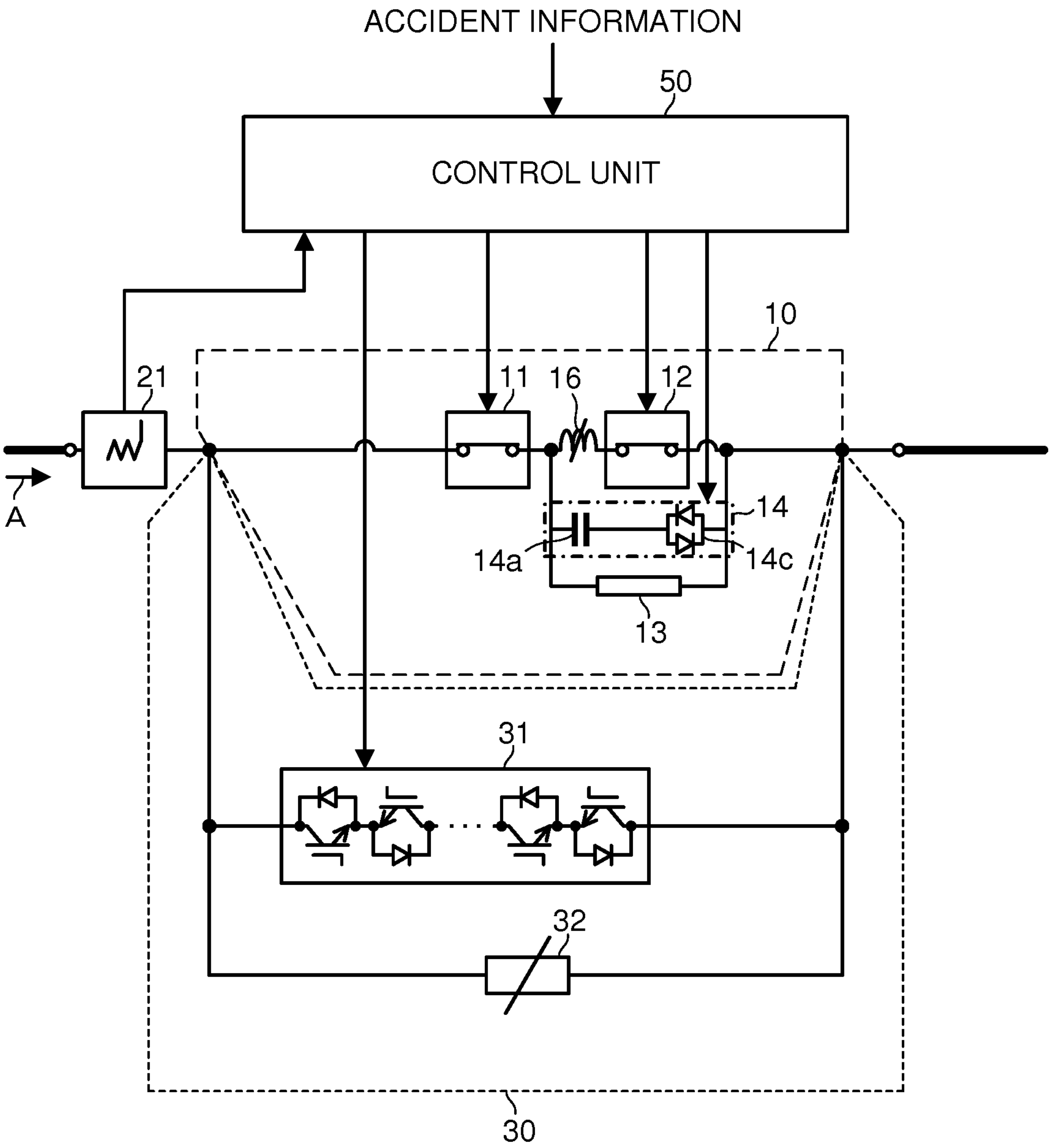
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FIG. 14

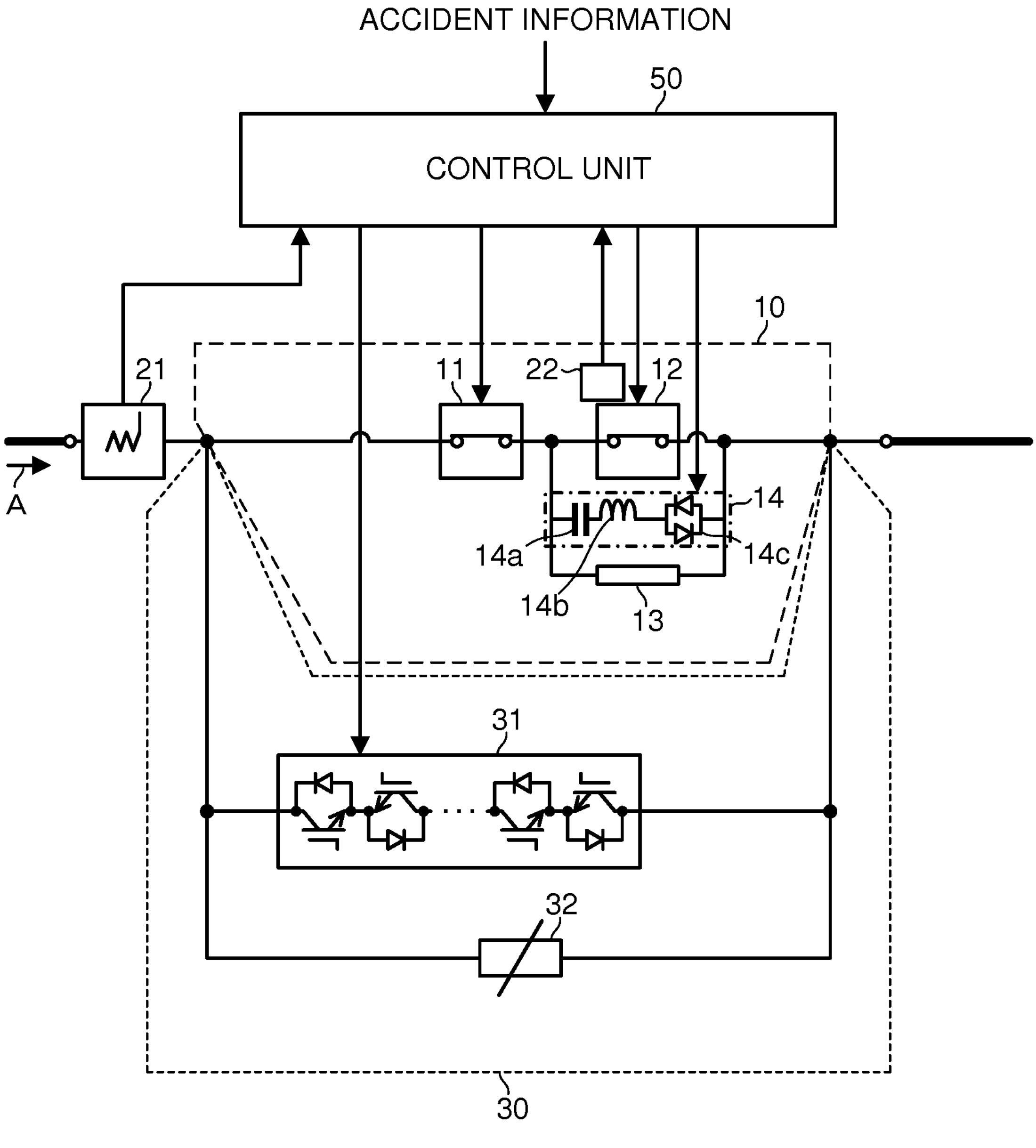
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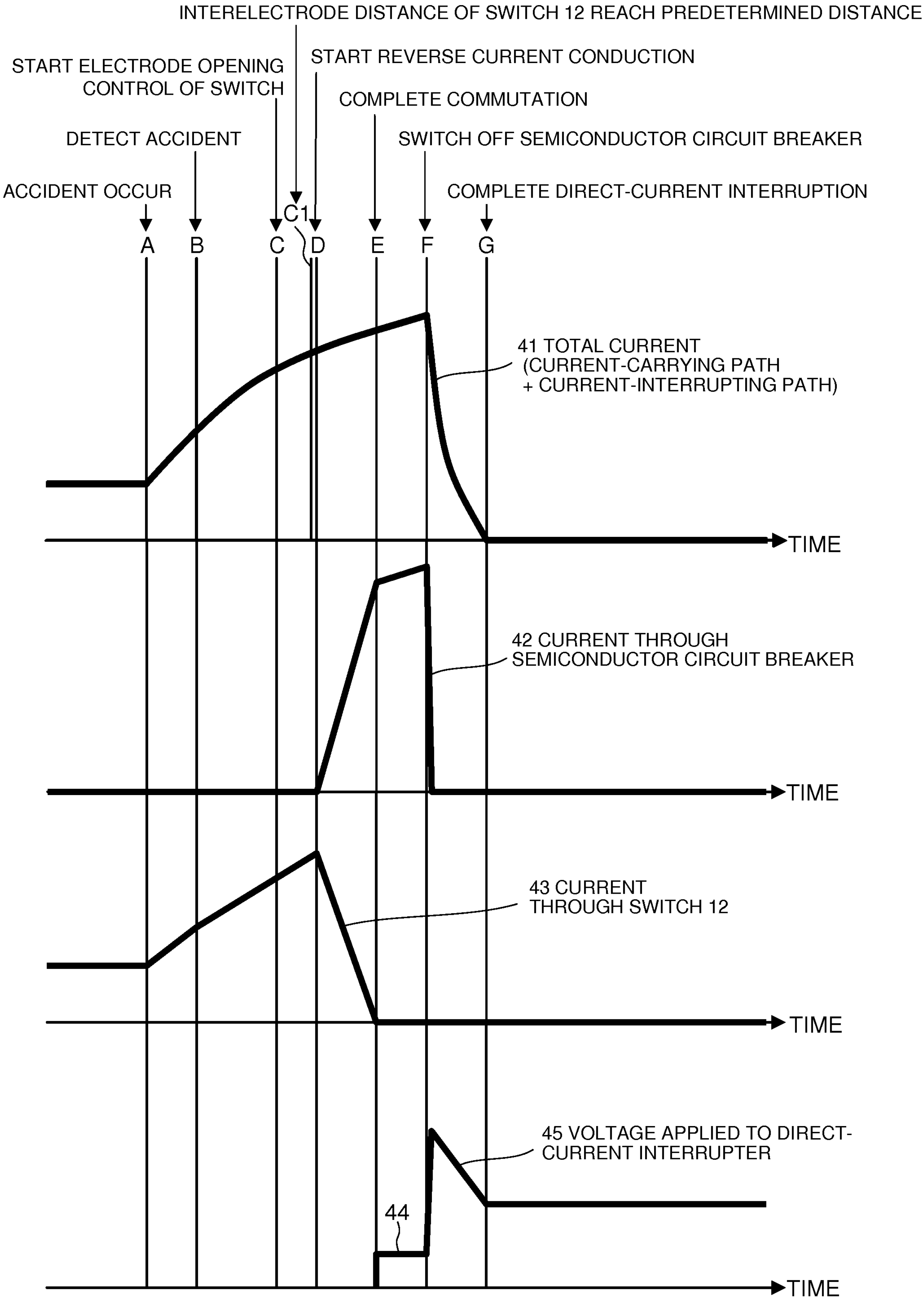
FIG. 15


INTERELECTRODE DISTANCE OF SWITCH 12 REACH PREDETERMINED DISTANCE
START ELECTRODE OPENING CONTROL OF SWITCH
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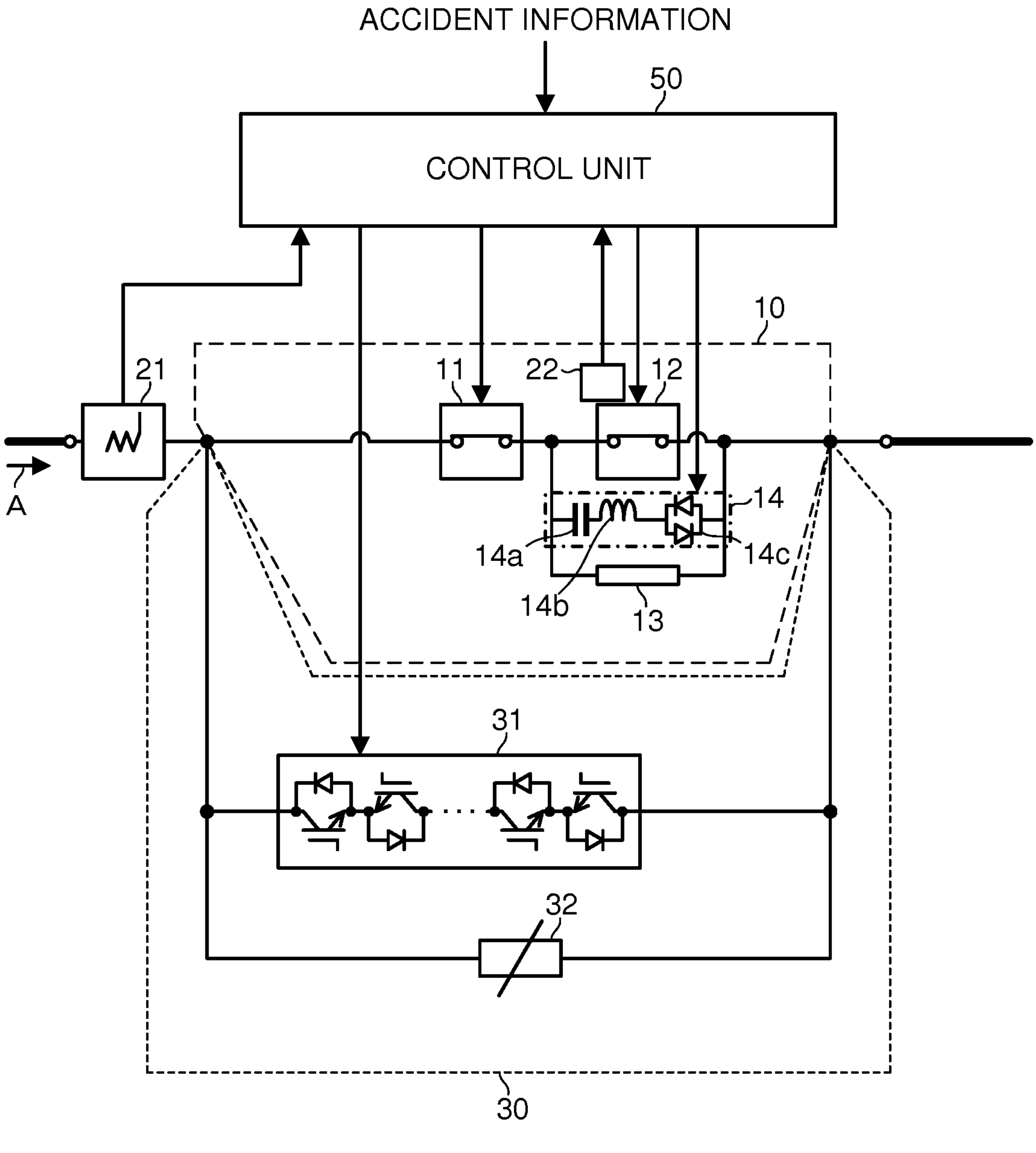
COMPLETE COMMUTATION
DETECT ACCIDENT
SWITCH OFF SEMICONDUCTOR CIRCUIT BREAKER
ACCIDENT OCCUR
COMPLETE DIRECT-CURRENT INTERRUPTION
C1
A
B
C
D
E
F
G
41 TOTAL CURRENT (CURRENT-CARRYING PATH + CURRENT-INTERRUPTING PATH)
TIME
42 CURRENT THROUGH SEMICONDUCTOR CIRCUIT BREAKER
TIME
43 CURRENT THROUGH SWITCH 12
TIME
45 VOLTAGE APPLIED TO DIRECT-CURRENT INTERRUPTER
44
TIME

FIG. 16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12
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32
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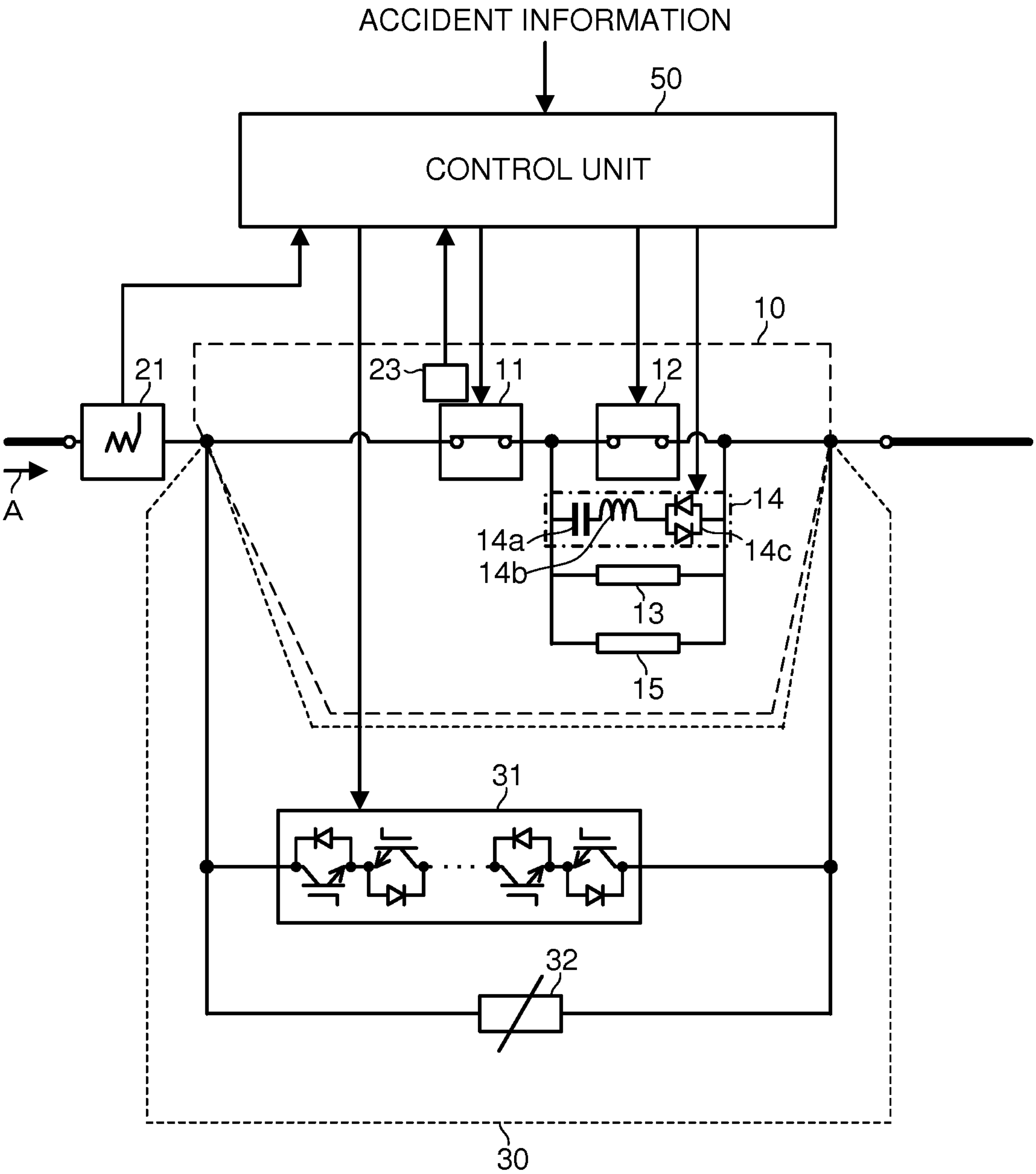
FIG. 17


ACCIDENT INFORMATION
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CONTROL UNIT
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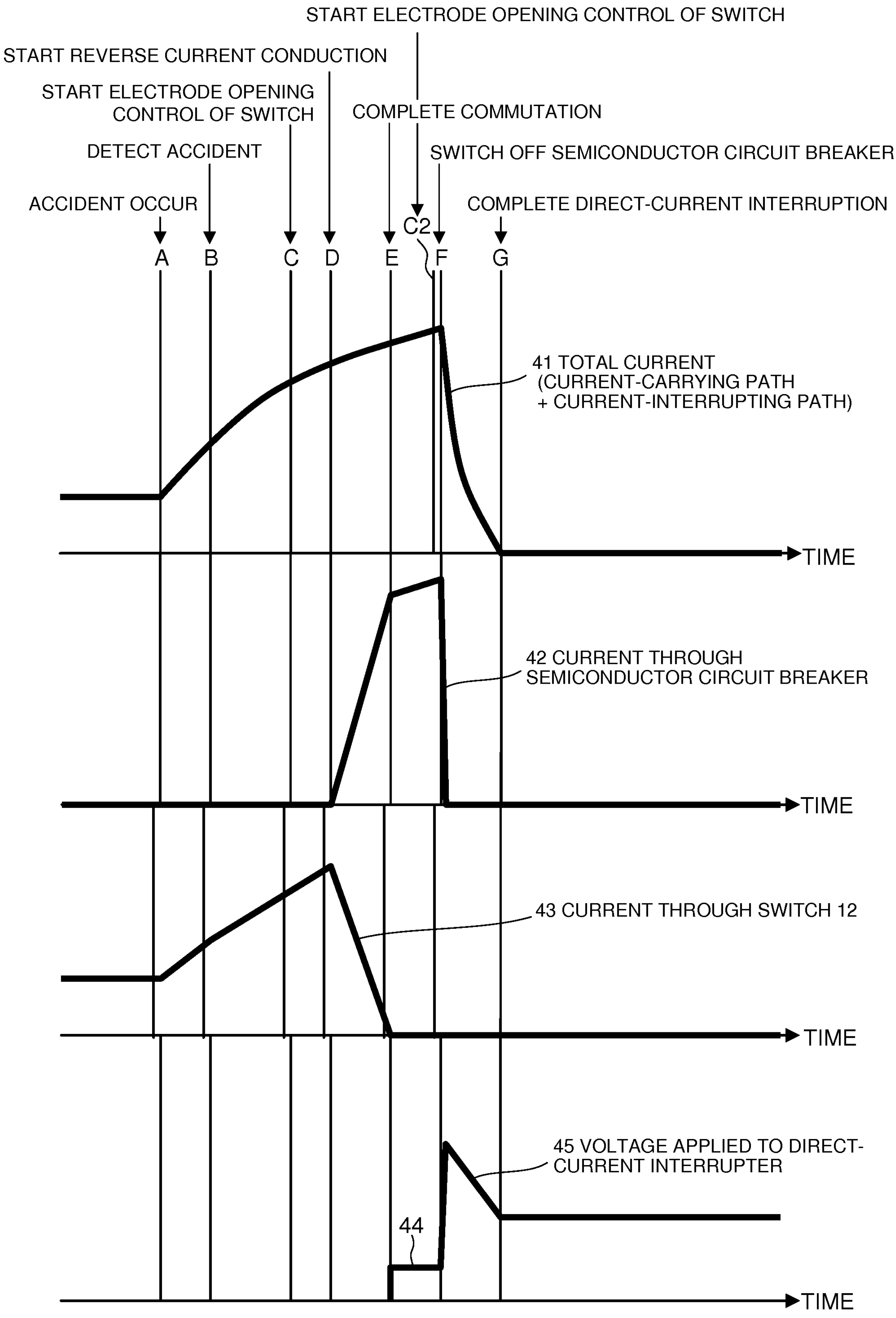
30

FIG. 18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COMPLETE COMMUTATION
DETECT ACCIDENT
SWITCH OFF SEMICONDUCTOR CIRCUIT BREAKER
ACCIDENT OCCUR
COMPLETE DIRECT-CURRENT INTERRUPTION
C2
A
B
C
D
E
F
G
41 TOTAL CURRENT (CURRENT-CARRYING PATH + CURRENT-INTERRUPTING PATH)
TIME
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43 CURRENT THROUGH SWITCH 12
TIME
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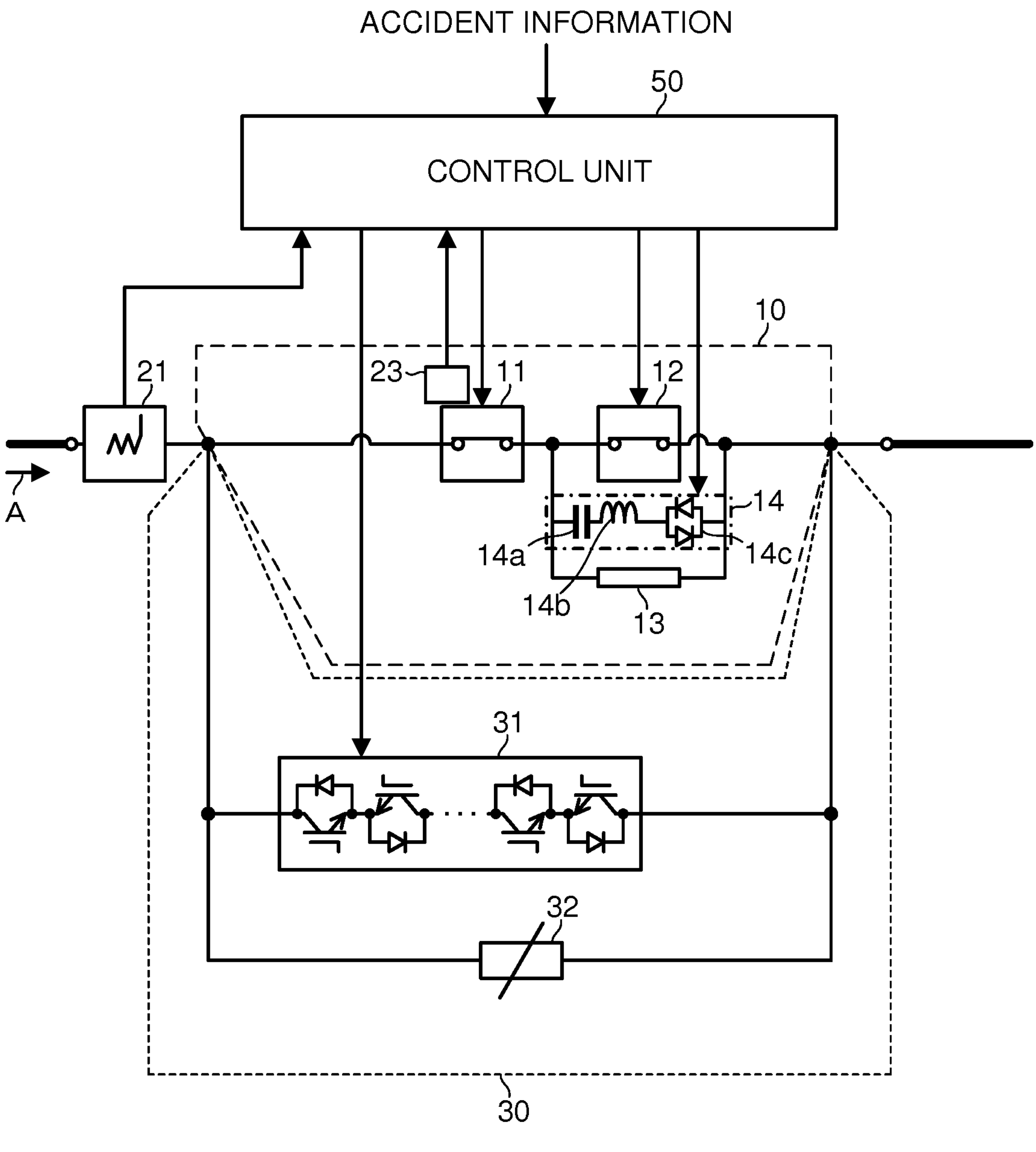
TIME

FIG. 19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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/001649

A. CLASSIFICATION OF SUBJECT MATTER
H01H33/59(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

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.
A	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), entire text; all drawings (Family: none)	1-17
A	JP 55-126923 A (Tokyo Shibaura Electric Co., Ltd.), 01 October 1980 (01.10.1980), entire text; all drawings (Family: none)	1-17

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

* Special categories of cited documents:
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"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
07 June 2016 (07.06.16)	21 June 2016 (21.06.16)

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

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

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2016/001649

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4-259719 A (Hitachi, Ltd.), 16 September 1992 (16.09.1992), paragraphs [0022], [0029] to [0030]; fig. 1, 4 (Family: none)	4-8
A	JP 9-17294 A (Mitsubishi Electric Corp.), 17 January 1997 (17.01.1997), paragraph [0025]; fig. 1 (Family: none)	5
E,X	WO 2016/047209 A1 (Mitsubishi Electric Corp.), 31 March 2016 (31.03.2016), paragraphs [0032] to [0038], [0044] to [0047], [0062] to [0064], [0070] to [0071]; fig. 3 to 4, 10, 12 (Family: none)	1-17

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

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **JUERGEN HAEFNER ; BJOERN JACOBSON.** Proactive Hybrid HVDC Breakers - A key innovation for reliable HVDC grids. *Cigre, The electric power system of the future - Integrating supergrids and microgrids International Symposium,* 13 September 2011 **[0007]**
- **PER SKARBY ; UELI STEIGER.** An Ultra-fast Disconnecting Switch for a Hybrid HVDC Breaker - a technical breakthrough. *Cigre, Canada conference, Calgary, Canada 9-11 September, 2013,* 09 September 2013 **[0007]**