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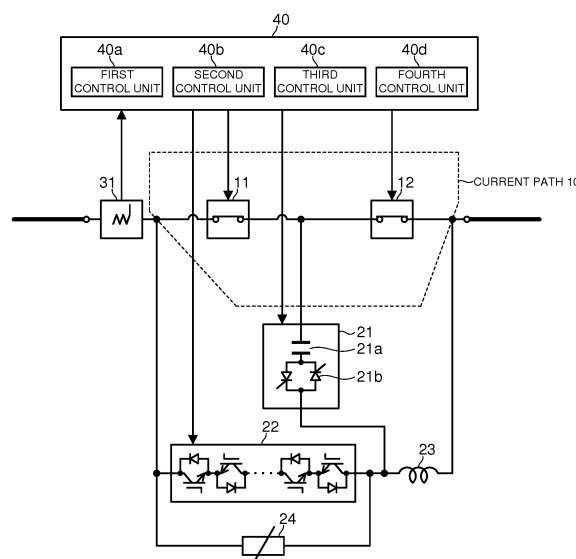
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(54) **DIRECT-CURRENT INTERRUPTION APPARATUS, DIRECT-CURRENT INTERRUPTION METHOD**

(57) A direct-current interruption apparatus of an embodiment includes a current path, a commutation element including a first semiconductor switch, a second semiconductor switch, a conductive path, and a nonlinear resistor. The current path includes a first switch and a second switch which are non-semiconductor devices and connected in series, the first switch having a first withstand voltage, and the second switch having a lower withstand voltage than the first withstand voltage. The commutation element has one end connected with a connection node of the first switch and the second switch and includes an element having a charge/discharge function and connected in series with the first semiconductor switch. The second semiconductor switch is between and connects with the other end of the commutation element and one end of the first switch which is opposite to the other end of the first switch connected with the second switch.

FIG. 1



Description

TECHNICAL FIELD

[0001] Embodiments of the present invention relate to a direct-current interruption apparatus and a direct-current interruption method for interrupting a direct current.

BACKGROUND ART

[0002] A system for transmitting electric power is typically required to have a function of interrupting a power transmission current in case of, for example, a fault. An interruption apparatus is used for this purpose, but direct-current power transmission, in particular, has a difficulty that alternating-current interruption does not have because a direct current transmitted in the direct-current power transmission does not have a zero point.

[0003] A currently used direct-current interruption apparatus includes, for example, a current path having a switch and a current-interrupting path which is in parallel with the current path and is capable of gradually decreasing a current. The switch on the current path is normally closed to allow the passage of the current through the current path.

When a fault occurs, the current-interrupting path temporarily becomes electrically open so as to allow a fault current to pass through the current-interrupting path instead of the current path. On the other hand, the switch is opened to interrupt the current flowing to the current path, thereby commutating the fault current toward the current-interrupting path. The current of the current-interrupting path is thereafter quickly limited. This is the completion of the interruption.

[0004] The current path of the direct-current interruption apparatus preferably has as small an electric resistance as possible. This is because the electric resistance is a power loss during the normal time. In the direct-current interruption apparatus, the switching of the direction of the current from the current path to the current-interrupting path is preferably as prompt as possible. This is because, as the switching is more delayed, the fault current increases more, leading to an increase in a value of the current that is to be interrupted by the current-interrupting path. The increase in the current to be interrupted necessitates a larger capacity of the current-interrupting path, leading to a size increase of the interruption apparatus.

PRIOR ART DOCUMENT

NON-PATENT DOCUMENT

[0005]

Non-patent Document 1: Juergen Haefner, Bjoern Jacobson, "Proactive Hybrid HVDC Breakers - A key innovation for reliable HVDC grids", 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", Ciger, Canada conference, Calgary, Canada 9-11 September, 2013

10 SUMMARY OF THE INVENTION

TECHNICAL PROBLEM

[0006] A problem to be solved by the invention is to provide a direct-current interruption apparatus and a direct-current interruption method which enable to reduce a power loss during the normal time and avoid an increase in apparatus size.

20 SOLUTION TO PROBLEM

[0007] A direct-current interruption apparatus of an embodiment includes a current path, a commutation element including a first semiconductor switch, a second semiconductor switch, a conductive path, and a nonlinear resistor. The current path includes a first switch and a second switch connected in series, the first switch being a non-semiconductor device and having a predetermined first withstand voltage, and the second switch being a non-semiconductor device and having a second withstand voltage lower than the first withstand voltage.

[0008] The commutation element has one end connected with a connection node of the first switch and the second switch and includes a functional element and the first semiconductor switch connected in series, the functional element having a charge/discharge function. The second semiconductor switch is between and connects with the other end of the commutation element and one end of the first switch, opposite to one end of the first switch connected with the second switch. The conductive path is between and connects with the other end of the commutation element and one end of the second switch, opposite to one end of the second switch connected with the first switch. The nonlinear resistor is connected in parallel with the second semiconductor switch.

[0009] A direct-current interruption method of an embodiment is a direct-current interruption method of the above-described direct-current interruption apparatus and is as follows. Specifically, the method includes (1) charging the functional element of the commutation element in advance, (2) discharging the functional element after starting electrode open control over the first switch and starting electrode open control over the second switch, (3) changing the first semiconductor switch to OFF after discharging the functional element, and (4) changing the second semiconductor switch to OFF after changing the first semiconductor switch to OFF.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a block diagram illustrating a direct-current interruption apparatus of a first embodiment.

Fig. 2A is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 1 (total current).

Fig. 2B is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 1 (current of a switch 12).

Fig. 2C is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 1 (current of a switch 11).

Fig. 2D is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 1 (applied voltage to the direct-current interruption apparatus).

Fig. 3 is a sectional view schematically illustrating a vacuum valve being an element that may be included in the switch 12 illustrated in Fig. 1.

Fig. 4 is a perspective view schematically illustrating a modification example of electrodes of the vacuum valve illustrated in Fig. 3.

Fig. 5 is a block diagram illustrating a direct-current interruption apparatus of a second embodiment (No. 1).

Fig. 6 is a block diagram illustrating a direct-current interruption apparatus of the second embodiment (No. 2).

Fig. 7 is a block diagram illustrating a direct-current interruption apparatus of a third embodiment.

Fig. 8 is a block diagram illustrating a direct-current interruption apparatus of a fourth embodiment.

Fig. 9A is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 8 (total current).

Fig. 9B is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 8 (current of a switch 12).

Fig. 9C is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 8 (current of a switch 11).

Fig. 9D is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 8 (applied voltage to the direct-current interruption apparatus).

Fig. 10 is a block diagram illustrating a direct-current interruption apparatus of a fifth embodiment.

Fig. 11A is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 10 (total current).

Fig. 11B is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 10 (current of a switch 12).

Fig. 11C is an explanatory timing chart of the operation of the direct-current interruption apparatus il-

lustrated in Fig. 10 (current of a switch 11).

Fig. 11D is an explanatory timing chart of the operation of the direct-current interruption apparatus illustrated in Fig. 10 (applied voltage to the direct-current interruption apparatus).

DESCRIPTION OF EMBODIMENTS

(First Embodiment)

[0011] Based on the above, a direct-current interruption apparatus of each embodiment will be hereinafter described with reference to the drawings. Fig. 1 illustrates the configuration of the direct-current interruption apparatus of a first embodiment. As illustrated in Fig. 1, the direct-current interruption apparatus includes a current path 10, a commutation element 21, a semiconductor switch 22, a reactor 23, a nonlinear resistor 24, a current detecting unit 31, and a control unit 40. The commutation element 21 includes a charge/discharge functional element 21a and a semiconductor switch 21b connected in series.

[0012] The current path 10 includes a switch 11 and a switch 12 connected in series, the switch 11 having a predetermined large withstand voltage characteristics (to be described later) and the switch 12 having a lower withstand voltage characteristics than that of the switch 11. The switches 11, 12 are both non-semiconductor devices, and out of the switch 11 and the switch 12, the switch 12 is higher in responsiveness to electrode open control. However, being a non-semiconductor device, even the switch 12 is not capable of responding as quickly as a semiconductor device. In the following description, the switch 11 and the switch 12 will be sometimes comprehensively referred to as a switch group.

[0013] The operation of this apparatus is roughly as follows. The switches 11, 12 are normally both closed to pass a current through the current path 10. When the interruption of the current is required because of, for example, a fault, the electrode open control over the switches 11, 12 is promptly started, and according to the switch 12 reaching the electrode open state first, the commutation element 21 is made to function to promptly commute the current flowing to the switch 12 to a path passing the commutation element 21.

[0014] Immediately after the commutation, the electrode open control over the switch 11 has not been completed and the current flows to the switch 11. Thereafter, when the semiconductor switch 21b of the commutation element 21 is promptly changed to OFF, the current which continues flowing to the switch 11 is commutated to a path passing the semiconductor switch 22 which has been controlled so as to allow the passage of the current. Thereafter, when the semiconductor switch 22 is changed to OFF, the current is limited. This is the completion of the interruption.

[0015] In Fig. 1, both cases are generally conceivable where the flow direction of a direct current during the

normal time is left to right in the drawing and it is right to left in the drawing, and the direct-current interruption apparatus is adapted to the both cases. For the convenience of the description, it is hereinafter assumed that the flow direction of the direct current is normally from left to right in the drawing. First, the components illustrated in Fig. 1 will be described.

[0016] The switch 11 is, as described above, a non-semiconductor device (mechanical device) and is capable of switching between the passage and interruption of a current. The switch 12 is also a non-semiconductor device and is capable of switching between the passage and interruption of a current. The switch 11 and the switch 12 are in a complementary relation in terms of their advantages of withstand voltage characteristics and response speed to the electrode open control, and the switches thus having different characteristics are connected in series so that they each take its share of functions. The opening and closing of electrodes of both the switch 11 and the switch 12 are controlled by the control unit 40.

[0017] The commutation element 21 has one end connected with a connection node of the switch 11 and the switch 12 to commutate the current flowing to the switch 12 quickly to the path passing the commutation element 21 (and the reactor 23). The commutation element 21 includes a charge/discharge functional element 21a (for example, a capacitor) and a semiconductor switch 21b connected in series.

[0018] The charge/discharge functional element 21a is charged in advance under the control by the control unit 40, and when the semiconductor switch 21b changes to ON in this state, a discharge of stored charge occurs to decrease a voltage across electrodes of the charge/discharge functional element 21a toward zero, so that the current flowing to the switch 12 is quickly commutated to be a current passing the commutation element 21. The charging and discharging of the commutation element 21 are controlled by the control unit 40.

[0019] The semiconductor switch 22 is between and connects with the other end of the commutation element 21 and one end of the switch 11, opposite to one end of the switch 11 connected with the switch 12. The semiconductor switch 22 switches between the passage and interruption of a current and its switching (ON/OFF) is controlled by the control unit 40.

[0020] A specific example of the semiconductor switch 22 is a structure including many series-connected unit elements and having two main electrode terminals as a whole, the unit elements each being an element in which two inverse parallel connection (parallel connection with opposite forward directions) elements each composed of an IGBT (insulated gate bipolar transistor) and a diode are in face-to-face series connection in opposite directions, as illustrated in Fig. 1. When a voltage ascribable to a control signal from the control unit 40 is applied to gates of IGBTs, the unit elements get into a state where the current flows in any direction (that is, the ON state).

[0021] As a specific structure of the semiconductor switch 22, various structures are adoptable besides the illustrated one. For example, adoptable is a structure composed of many series-connected unit elements and having two main electrode terminals as a whole, the unit elements each being composed of thyristors which are in inverse parallel connection. A semiconductor switch typically has an equivalent resistance in an ON state (on-resistance), and undergoes a voltage drop when supplied with a current. This voltage drop is larger depending on the number of the series-connected unit elements, that is, the on-resistance of the whole semiconductor switch 22 also is larger depending on this series-connection number.

[0022] The necessary number of the series-connected unit elements can be decided so as to satisfy the condition that it can endure a high voltage that is possibly applied to the interruption apparatus at and after an instant when the semiconductor switch 22 becomes OFF for the current interruption. To achieve this, the series-connection number usually needs to be large to a certain degree (for example, several hundreds).

[0023] A standard way of the switching control over the semiconductor switch 22 by the control unit 40 is to keep the semiconductor switch 22 OFF during the normal time, temporarily change the semiconductor switch 22 to ON at the time of the interruption operation, and thereafter quickly change the semiconductor switch 22 to OFF. However, this is not restrictive. Even if the semiconductor switch 22 is controlled to be kept ON during the normal time, its on-resistance prevents a current from actually flowing thereto, and the total current flows in the current carrying path 10. Therefore, the control to thus keep the semiconductor switch 22 ON during the normal time is also an adoptable selection.

[0024] The reactor 23 is between and connected with the other end of the commutation element 21 and one end of the switch 12, opposite to one end of the switch 12 connected with the switch 11. The purpose of the inserted reactor 23 is to adjust the time from the start of the discharging of the commutation element 21 up to an instant at which the current of the switch 12 is reduced to zero. The timing at which the current is reduced to zero is preferably after the completion and establishment of the electrode open control over the switch 12, and by disposing the reactor 23 in the illustrated manner and adjusting its reactance, it is possible to reduce a discharge current to enable the aforesaid adjustment. In a case where the necessity for the adjustment is low, a simple conducting wire may replace the reactor 23.

[0025] The nonlinear resistor 24 is connected in parallel with the semiconductor switch 22. The nonlinear resistor 24 functions at a final stage of the interruption operation of the direct-current interruption apparatus. Specifically, when the current to the current path 10 is interrupted and the current to the semiconductor switch 22 is also interrupted, the current temporarily flows to the nonlinear resistor 24. At an initial stage of the temporary flow,

a current having the same value as that of the current flowing to the semiconductor switch 22 immediately before this stage flows. When the current flows, a resistance value increases due to the nonlinearity of resistance, and the increased resistance value causes the current to be substantially zero. This is the completion of the current interruption.

[0026] The current detecting unit 31 detects a current flowing in the direct-current interruption apparatus and notifies the control unit 40 of the detected current. For this purpose, the current detecting unit 31 is outside the parallel connection of the switches 11, 21, the semiconductor switch 22, and the nonlinear resistor 24 so as to be connected in series with this parallel connection. Specific examples of how the current is detected include a structure to insert a resistor having a very small resistance value and detect a voltage across the resistor, and a structure to detect a magnetic flux generated by the current (direct-current CT).

[0027] The control unit 40 controls the opening and closing of the electrodes of the switches 11, 21, the charging and discharging of the commutation element 21, and ON/OFF of the semiconductor switch 22. The control unit 40 includes, as lower-order control units corresponding to these controls, a first control unit 40a, a second control unit 40b, a third control unit 40c, and a fourth control unit 40d, and among these lower-order control units, information necessary for their controls is transmitted so as to be shared among them.

[0028] The first control unit 40a connects with the switch 11 to control the opening and closing of the electrodes of the switch 11. The second control unit 40b connects with the switch 12 to control the opening and closing of the electrodes of the switch 12. The third control unit 40c connects with the commutation element 21 and the first and second control units 40a, 40b. The third control unit 40c controls ON/OFF of the semiconductor switch 21b of the commutation element 21 and also has a control function of charging the charge/discharge functional element 21a of the commutation element 21 in advance and discharging it at a predetermined timing.

[0029] The third control unit 40c has at least the following functions. Specifically, the third control unit 40c performs the charge control for charging the charge/discharge functional element 21a in advance before the start of the electrode open control over the switch 11 by the first control unit 40a and the start of the electrode open control over the switch 12 by the second control unit 40b, performs the discharge control for discharging the charge/discharge functional element 21a after the start of the electrode open control over the switch 11 by the first control unit 40a and the start of the electrode open control over the switch 12 by the second control unit 40b, and performs the OFF control for changing the semiconductor switch 21b to OFF after performing the discharge control.

[0030] The discharge control that the third control unit 40c performs after the start of the electrode open control

over the switch 11 by the first control unit 40a and the electrode open control over the switch 12 by the second control unit 40b takes place at or after the opening time at which the interelectrode distance of the switch 12 is assumed to reach a predetermined distance.

[0031] The OFF control that the third control unit 40c performs after performing the control for discharging the charge/discharge functional element 21a takes place at or after the commutation time at which the current flowing in the switch 12 is assumed to reach substantially zero.

[0032] The fourth control unit 40d connects with the semiconductor switch 22 and the third control unit 40c and controls ON/OFF of the semiconductor switch 22. The fourth control unit 40d at least has a function of performing the control for changing the semiconductor switch 22 to OFF after the third control unit 40c performs the OFF control.

[0033] The control for changing the semiconductor switch 22 to OFF performed by the fourth control unit 40d after the third control unit 40c performs the OFF control takes place at or after the opening time at which the interelectrode distance of the switch 11 is assumed to reach a predetermined distance.

[0034] The control unit 40 obtains information regarding a fault from a fault detector (not illustrated), but the control unit 40 may determine that a fault has occurred by making use of the detected current notified from the current detecting unit 31.

[0035] Fig. 2A to Fig. 2D illustrate timing charts of the operations of the direct-current interruption apparatus illustrated in Fig. 1. The time-series operations of the direct-current interruption apparatus illustrated in Fig. 1 will be described with reference to Fig. 2A to Fig. 2D.

[0036] Fig. 2A illustrates a time-series variation of the total current (that is, the current detected by the current detecting unit 31). In Fig. 2A, the initial stage (stage before the time A is a normal state where a current is flowing, and this current is the total current flowing in the switches 11, 12. Naturally, in the stage before the time A, the current does not flow to the semiconductor switch 22, nor to the commutation element 21, the reactor 23, or the nonlinear resistor 24.

[0037] When a fault occurs in a direct-current power transmission system at the time A, the total current gradually increases as illustrated in Fig. 2A. The control unit 40 finds that a fault has occurred from the information obtained from the fault detector (not illustrated) or from the detected current notified by the current detecting unit 31 (time B). Upon finding the fault occurrence, the control unit 40 starts the electrode open control over the switches 11, 21 (time C). Even when the electrode open control is started, an arc current continues flowing to the switches 11, 12. In this state, the discharging of the commutation element is started under the control by the control unit 40 (time D).

[0038] The discharging of the commutation element 21 is started, specifically, by changing the semiconductor switch 21b to ON. When the semiconductor switch 21b

changes to ON, the discharge of the electric charge stored in the charge/discharge functional element 21a in advance occurs to decrease the voltage across the both electrodes of the charge/discharge functional element 21a toward zero, so that the current flowing to the switch 12 is quickly commutated to be the current passing the commutation element 21. More specific description will be given below.

[0039] A state where the electrodes on the lower side and the upper side in the drawing of the charge/discharge functional element 21a are charged plus and minus respectively in advance and the semiconductor switch 21b is OFF is equivalent to a state where one of the electrodes of the charge/discharge functional element 21a is electrically open, and in this state, the discharge scarcely occurs. When the semiconductor switch 21b changes to ON from this state, the discharge occurs from the electrode on the lower side in the drawing of the charge/discharge functional element 21a to the electrode on the upper side in the drawing of the charge/discharge functional element 21a through the semiconductor switch 21b, the reactor 23, and the switch 12.

[0040] In the switch 12, the direction of this discharge current is opposite to that of the current having been flowing until then, and accordingly, the current having been flowing to the switch 12 is quickly commutated to be the current passing the commutation element 21. Consequently, the current interruption of the switch 12 is completed (time E: refer to Fig. 2B).

[0041] At or after the time D at which the discharging of the commutation element 21 is started, a voltage starts to be generated across the switch 12 owing to an on-resistance of the semiconductor switch 21b (refer to Fig. 2D). The length from the time D to the time E is adjustable by the inductance of the reactor 23 as roughly described above. However, since at or after the time D, the voltage can be generated across the switch 12, the time D is preferably at or after the opening time at which the interelectrode distance of the switch 12 is assumed to reach the predetermined distance.

[0042] Even after the aforesaid time E, the current continues flowing to the switch 11 because of its low responsiveness to the electrode open control (refer to Fig. 2C). In this state, the semiconductor switch 21b of the commutation element 21 is next changed to OFF under the control by the control unit 40 (time F). That is, the control unit 40 estimates the length from the time D to the time E and performs the OFF control over the semiconductor switch 21b at or after the commutation time (time E) at which the current flowing in the switch 12 is assumed to reach zero.

[0043] By the OFF control over the semiconductor switch 21b by the control unit 40, the current path leading to the semiconductor switch 21b through the switch 11 is disconnected. Accordingly, the current having been flowing to the switch 11 until then is commutated this time to be a current to the semiconductor switch 22 which has been brought into a state allowing the current passage

(time F: refer to Fig. 2C). In a period from about the time F up to the time G described next, the voltage drop to a certain degree is occurring in the semiconductor switch 22 owing to the on-resistance of the semiconductor switch 22, and this becomes an applied voltage to the direct-current interruption apparatus (refer to Fig. 2D).

[0044] After the time F, the control unit 40 controls the semiconductor switch 22 so as to turn off the semiconductor switch 22, at or after the opening time at which the interelectrode distance of the switch 11 is assumed to reach the predetermined distance (time G). At this time, the current path 10 having the switches 11, 12 has already been in the current interruption state which is established at a timing soon after the time F, and the semiconductor switch 22 is also changed to the current interruption state at the time G. Accordingly, at and after the time G, the current temporarily flows to the nonlinear resistor 24.

[0045] At the initial stage of the temporary flow, the current having the same value as that of the current flowing to the semiconductor switch 22 immediately before this stage flows. Consequently, a relatively large voltage drop (for example, 500 kV) occurs in the nonlinear resistor 24. When the current flows to the nonlinear resistor 24, its resistance value increases owing to the nonlinearity of the resistance, and the increased resistance value decreases the current to substantially zero. This is the completion of the current interruption (time H: for example, several ms from the time A). A state from the time H is a state where a direct-current voltage (for example, 300 kV) appropriate for the direct-current power transmission system is applied to the direct-current interruption apparatus (refer to Fig. 2D).

[0046] The above-described time-series controls by the control unit 40 enable a series of the interruption controls as the direct-current interruption apparatus. This control procedure can be said as a basic procedure in this direct-current interruption apparatus, and the controls for the interruption may take place at more precise preferable timings without departing from this basic procedure (to be described later).

[0047] As described hitherto, according to the direct-current interruption apparatus of this embodiment, the non-use of a semiconductor switch in the current path 10 makes it possible to greatly reduce a power loss during the current passage. The switch 11 is lower in responsiveness to the electrode open control but is higher in withstand voltage characteristics than the switch 12. Conversely, the switch 12 is higher in responsiveness to the electrode open control but is lower in withstand voltage characteristics than the switch 11. The series connection of the high-withstand voltage switch 11 with the low-withstand voltage switch 12 achieves a withstand voltage high enough as the direct-current interruption apparatus.

[0048] The commutation element 21 inserted in parallel with the switch 12 works to forcibly commutate the current of the switch 12 quickly to the commutation ele-

ment 21 according to the switch 12 high in responsiveness. When the semiconductor switch 21b of the commutation element 21 is thereafter changed to OFF, it is possible to quickly commutate the current of the switch 11 this time toward the semiconductor switch 22 as a current to be interrupted. Accordingly, it is possible to change the semiconductor switch 22 to OFF before the value of the interruption target current commutated to the second semiconductor switch 22 increases very much. This enables to avoid an increase in size of the interruption apparatus.

[0049] Fig. 3 is a sectional view schematically illustrating a vacuum valve being an element that may be included in the switch 12 illustrated in Fig. 1. As illustrated in Fig. 3, the vacuum valve 50 includes, as its main components, a porcelain tube 51, a fixed-side electrode 52, a movable-side electrode 53, a fixed-side current-carrying shaft 54, a movable-side current-carrying shaft 55, and a bellows 56.

[0050] Though specific examples of the switch 12 are not mentioned in the description of Fig. 1 and Fig. 2A to Fig. 2D, a vacuum switch is usable as the switch 12. The vacuum switch is relatively high in responsiveness though it cannot be generally said to be a switch having a high withstand voltage characteristics. Therefore, even if the vacuum switch is used as the switch 12, the switch 12 can endure a low applied voltage which is possibly generated by the commutation element 21 including the semiconductor switch 21b in an ON state after the current of the current path 10 is reduced to zero, and in addition, there is an advantage that it is possible to reduce the time required for the commutation of the current of the switch 12.

[0051] The vacuum switch includes the vacuum valve 50 illustrated in Fig. 3, and in addition includes a mechanism (not illustrated) for moving the movable-side current-carrying shaft 55 in its axial direction as desired. The inside of the cylindrical porcelain tube 51 is kept substantially vacuum, and in order to insulate this vacuum from the outside, the bellows 56 is fixed to the movable-side current-carrying shaft 55 and the porcelain tube 51. The structure of the vacuum valve 50 will be described below.

[0052] The fixed-side current-carrying shaft 54 penetrates through an upper surface of the cylindrical porcelain tube, and the fixed-side current-carrying shaft 54 is fixed to the porcelain tube 51 at a portion where it penetrates to the porcelain tube 51. In the fixed-side current-carrying shaft 54, a portion penetrating to and protruding from the upper surface of the cylindrical porcelain tube 51 is one terminal of the switch. The flat and disk-shaped fixed-side electrode 52 is at one end of the fixed-side current-carrying shaft 54 located inside the porcelain tube 51, so as to be coaxial with the fixed-side current-carrying shaft 54. A face of the movable-side electrode 53 having the same shape as that of the fixed-side electrode 52 and coaxial with the fixed-side electrode 52 faces a face of the fixed-side electrode 52 on a side opposite to a side where the fixed-side current-carrying shaft 54

is located.

[0053] The movable-side current-carrying shaft 55 is located on a side of the movable-side electrode 53 opposite to its face facing the fixed-side current-carrying shaft 54, so as to be coaxial with the fixed-side current-carrying shaft 54, the fixed-side electrode 52, and the movable-side electrode 53. The movable-side current-carrying shaft 55 penetrates through a lower surface of the cylindrical porcelain tube 51, and its portion penetrating and protruding is the other terminal of the switch. As already described, the bellows 56 has its one side fixed to the movable-side current-carrying shaft 55 and has the other end fixed to the porcelain tube 51. The bellows 56 constantly keeps the inside of the porcelain tube 51 airtight even if the movable-side current-carrying shaft 55 is moved in its axial direction in order to pass or interrupt the current.

[0054] Assuming that the direct-current interruption apparatus illustrated in Fig. 1 is used in a system of, for example, about 300 kV direct current, it may almost suffice if the switch 12 can endure the voltage drop by the commutation element 21 including the semiconductor switch 21b in the ON state, considering the structure of this apparatus in which the high-withstand voltage switch 11 is connected in series with the switch 12. This voltage drop is estimated as several kV at the largest, and even the switch 12 being the vacuum switch can easily endure the voltage on this level. In addition, the use of the switch 12 being the vacuum switch enables a reduction in the time required for the commutation from the switch 12.

[0055] Among vacuum switches, one having plate electrodes as the electrodes 52, 53 is especially advantageous in terms of a reduction in a power loss during the current passage because of its low electric resistance in the closed state. In particular, a vacuum switch including vertical magnetic field electrodes as the electrodes 52, 53 can have improved interruption performance and its electrodes are less damaged because an arc current flowing between its electrodes after the electrode open control is controlled to diffuse by a vertical magnetic field.

[0056] Examples of the vertical magnetic field electrodes are a fixed-side electrode 52a and a current-carrying side electrode 53a having slits on their side faces so that a circumferential-direction component is added to the direction of the current as schematically illustrated in Fig. 4. When the current between the electrodes 52a, 53a has the circumferential component, the vertical magnetic field is added to the arc current between the electrodes 52a, 53a, and consequently, charged particles are confined in the magnetic field to equally distribute to the whole electrodes 52a, 53a. This can improve interruption performance and reduce damage to the electrodes.

[0057] A specific example of the switch 11 is not mentioned either in the description of Fig. 1 and Fig. 2A to Fig. 2D, but a gas switch filled with SF_6 as insulating gas is usable as the switch 11, for instance. The gas switch is typically high in withstand voltage characteristics. Therefore, the use of the gas switch as the switch 11

enables the switch 11 to receive and endure a high applied voltage to the direct-current interruption apparatus that is possibly generated after the current interruption. At this time, the high applied voltage to the direct-current interruption apparatus is borne mainly by the switch 11 since the commutation element 21 (its resistance is not infinitely large, though high) in the OFF state is in parallel with the other switch 12.

(Second Embodiment)

[0058] Next, a direct-current interruption apparatus of a second embodiment will be described with reference to Fig. 5 (No. 1) and Fig. 6 (No. 2). Fig. 5 illustrates the configuration of the direct-current interruption apparatus of the second embodiment (No. 1). In Fig. 5, the same components as those illustrated in Fig. 1 will be denoted by the same reference signs and description thereof will be omitted.

[0059] The configuration of this second embodiment is different from that illustrated in Fig. 1 in that the nonlinear resistor 24 in the second embodiment is connected in parallel with a series element of the semiconductor switch 22 and the reactor 23. The nonlinear resistor 24 may be connected in parallel only with the semiconductor switch 22 as illustrated in Fig. 1, and may alternatively be connected in parallel with the series element of the semiconductor switch 22 and the reactor 23 as described here.

[0060] The purpose of the reactor 23 is to adjust the time from the start of the discharging of the commutation element 21 until the current of the switch 12 is reduced to zero. On the other hand, to the nonlinear resistor 24, the current only temporarily flows at the final stage of the direct-current interruption. Therefore, in whichever manner the nonlinear resistor 24 is arranged, there is substantially no influence on the function of the temporary current flow, that is, the direct-current interruption operation.

[0061] Fig. 6 illustrates the configuration of the direct-current interruption apparatus of the second embodiment (No. 2). In Fig. 6, the same components as those illustrated in Fig. 1 will be denoted by the same reference signs and description thereof will be omitted.

[0062] The configuration of this second embodiment is different from that illustrated in Fig. 1 in that the reactor 23 of the second embodiment is inserted in series only with the commutation element 21. That is, the reactor 23 is not in a series positional relation with the semiconductor switch 22, nor with the nonlinear resistor 24. It can also be said that the commutation element 21 is replaced by a series connection element of the charge/discharge functional element 21a, the semiconductor switch 21b, and the reactor 23. The reactor 23 may also be in such an arrangement.

[0063] The purpose of the reactor 23 is to adjust the time from the start of the discharging of the commutation element 21 until the current of the switch 12 is reduced

to zero, which easily leads to the conclusion that the reactor 23 may be in the arrangement illustrated in Fig. 6.

(Third Embodiment)

[0064] Next, a direct-current interruption apparatus of a third embodiment will be described with reference to Fig. 7. Fig. 7 illustrates the configuration of the direct-current interruption apparatus of the third embodiment. In Fig. 7, the same components as those illustrated in Fig. 1 will be denoted by the same reference signs and description thereof will be omitted.

[0065] The configuration of the third embodiment is different from that illustrated in Fig. 1 in that a current path 10A of the third embodiment further includes an additional element 13 which is connected in parallel with the switch 12 and functions to reduce the maximum voltage that is possibly applied to the switch 12. Disposing the additional element 13 in parallel with the switch 12 makes it possible to further obviously reduce the maximum voltage applied to the switch 12, owing to its configuration difference from the switch 11 not provided with such an additional element.

[0066] As the additional element 13, one of a resistor, a nonlinear resistor, a capacitor, and a series connection element of a capacitor and a resistor, or one in which two or more these are connected in parallel is adoptable, for instance. In a case where the additional element 13 is a resistor or a nonlinear resistor (for example, a zinc oxide element), a resistance-divided voltage is applied to the switch 12, owing to its configuration difference from the switch 11 (small resistance, small applied voltage).

[0067] Similarly, in a case where the additional element 13 is a capacitor, a capacitance-divided voltage is applied to the switch 12, owing to its configuration difference from the switch 11 (large capacitance, small applied voltage). In a case where the additional element 13 is a series-connection element of a capacitor and a resistor, an impedance-divided voltage is applied to the switch 12, owing to its configuration difference from the switch 11 (small impedance, small applied voltage).

(Fourth Embodiment)

[0068] Next, a direct-current interruption apparatus of a fourth embodiment will be described with reference to Fig. 8. Fig. 8 illustrates the configuration of the direct-current interruption apparatus of the fourth embodiment. In Fig. 8, the same components as those illustrated in Fig. 1 will be denoted by the same reference signs and description thereof will be omitted.

[0069] The configuration of the fourth embodiment is different from that illustrated in Fig. 1 in that a current path 10B of the fourth embodiment includes a distance detecting unit 14 provided on the switch 11 to detect the interelectrode distance of the switch 11 and notify it to the control unit 40, and also includes a distance detecting unit 15 provided on the switch 12 to detect the interelec-

trode distance of the switch 12 and notify it to the control unit 40.

[0070] The distance detecting unit 14 provided on the switch 11 notifies the detected interelectrode distance of the switch 11 to the fourth control unit 40d.

[0071] The fourth control unit 40d performs the control for changing the semiconductor switch 22 to OFF at an instant that is after the third control unit 40c performs the OFF control for changing the semiconductor switch 21b to OFF and that is at or after the opening time at which the distance detecting unit 14 detects that the interelectrode distance of the switch 11 reaches a predetermined distance.

[0072] The distance detecting unit 15 provided on the second switch 12 notifies the detected interelectrode distance of the switch 12 to the third control unit 40c.

[0073] The third control unit 40c performs the discharge control at an instant that is after the first control unit 40a starts the electrode open control over the switch 11 and the second control unit 40b starts the electrode open control over the switch 12 and that is at or after the opening time at which the distance detecting unit 15 detects that the interelectrode distance of the switch 12 reaches a predetermined distance.

[0074] As described previously, when the control unit 40 performs the discharge control over the commutation element 21, the gradual reduction of the current flowing to the switch 12 starts and the application of the voltage to the switch 12 starts, as previously described. Therefore, according to this embodiment, since the control unit 40 is capable of performing the discharge control over the commutation element 21 based on the detected result of the interelectrode distance of the switch 12, the voltage is applied to the switch 12 having the interelectrode distance large enough for preventing a problem that might be caused by the generated voltage, and this is preferable.

[0075] When the control for changing the semiconductor switch 22 to OFF is performed, a path of the current flowing to the switch 11 is only the path passing the non-linear resistor 24 as previously described, and accordingly a very large voltage is applied to the direct-current interruption apparatus. According to this embodiment, since it is possible to perform the control for changing the semiconductor switch 22 to OFF based on the detected result of the interelectrode distance of the switch 11, the interelectrode distance of the switch 11 having a high withstand voltage characteristics has been opened to a predetermined distance at this instant, and this is preferable.

[0076] Fig. 9A to Fig. 9D illustrate timing charts of the operations of the direct-current interruption apparatus illustrated in Fig. 8. Fig. 9A to Fig. 9D are substantially the same as Fig. 2A to Fig. 2D, and for the same points, refer to the contents already described. The points described with reference to Fig. 8 will be described again with reference to Fig. 9. At the time D later than a timing at which the switch 12 is opened (= timing at which the withstand

voltage characteristics is obtained; time C1), the discharging of the commutation element 21 is started, and this is a preferable timing. Further, at the time G later than a timing at which the switch 11 is opened (= timing at which the withstand voltage characteristics is obtained; time C2), the semiconductor switch 22 is changed to OFF, and this is a preferable timing.

(Fifth Embodiment)

[0077] Next, a direct-current interruption apparatus of a fifth embodiment will be described with reference to Fig. 10. Fig. 10 illustrates the configuration of the direct-current interruption apparatus of the fifth embodiment. In Fig. 10, the same components as those illustrated in Fig. 1 will be denoted by the same reference signs and description thereof will be omitted.

[0078] The configuration of the fifth embodiment is different from that illustrated in Fig. 1 in that a current path 10C of the fifth embodiment includes a current detecting unit 16 connected in series with the switch 11 and detects the current flowing in the switch 11 to notify it to the control unit 40, and also includes a current detecting unit 17 connected in series with the switch 12 and detects the current flowing in the switch 12 to notify it to the control unit 40. As the specific configuration of the current detecting units 16, 17, the same configuration as that of the current detecting unit 31 is adoptable.

[0079] The current detecting unit 16 connected in series with the switch 11 and detects the current flowing in the switch 11 notifies the detected current to the fourth control unit 40d.

[0080] The fourth control unit 40d performs the control for changing the semiconductor switch 22 to OFF at an instant that is after the third control unit 40c performs the OFF control for changing the semiconductor switch 21a to OFF and that is at or after the commutation time at which the current detecting unit 16 detects that the current flowing in the switch 11 reaches zero.

[0081] The current detecting unit 17 connected in series with the switch 12 and detects the current flowing in the switch 12 notifies the detected current to the third control unit 40c.

[0082] The third control unit 40c performs the OFF control at an instant that is after the third control unit 40c performs the control for discharging the charge/discharge functional element 21a and that is at or after the commutation time at which the current detecting unit 17 detects that the current flowing in the switch 12 reaches zero.

[0083] The series connection of the current detecting unit 17 with the switch 12 has the following advantage. The control for discharging the functional element 21a of the commutation element 21 by the control unit 40 is performed so as to reduce the current flowing in the switch 12 to zero. Consequently, the commutation of the current flowing to the switch 12 is completed. It takes some time for the current flowing in the switch 12 to actually reach

zero after the discharge control. Therefore, it is preferable to perform the OFF control over the semiconductor switch 21b, which is the next control, taking this time into account. According to this embodiment, from the current detecting unit 17, it is possible to find that the current has reached zero, enabling a more appropriate response to this state.

[0084] The series connection of the current detecting unit 16 with the switch 11 has the following advantage. This configuration makes it possible to assume an instant at which the current detecting unit 11 detects that the current flowing in the switch 11 reaches zero, as an instant at which the interelectrode distance of the switch 11 has reached the predetermined distance. A reason for this is as follows. The electrode open control over the switch 11 and that over the switch 12 start simultaneously, though the switch 11 is lower in responsiveness to the electrode open control than the switch 12, and the controls are performed on the premise that the switch 12 reaches the electrode open state after the start of the electrode open control, and therefore at the instant at which the current detecting unit 16 thereafter detects that the current flowing in the switch 11 reaches zero, it is highly probable that the interelectrode distance of the switch 11 has already reached the predetermined distance.

[0085] Fig. 11A to Fig. 11D illustrate timing charts of the operations of the direct-current interruption apparatus illustrated in Fig. 10. Fig. 11A to Fig. 11D are almost the same as Fig. 2A to Fig. 2D, and for the same points, refer to the contents already described. The points described with reference to Fig. 10 will be described again with reference to Figs. 11. At the time F later than the timing at which the disconnection of the switch 12 is completed (= the current of the switch 12 is zero; time E), the commutation element 21 is controlled to be OFF. This is a preferable timing. Further, at the time G later than a timing at which the commutation to the semiconductor switch 22 is completed (= the current of the switch 11 is zero = assumed as the instant at which the interelectrode distance of the switch 11 has already reached the predetermined distance; time F1), the semiconductor switch 22 is changed to OFF. This is a preferable timing.

[0086] As has been described hitherto, according to the direct-current interruption apparatus of each of the embodiments, the non-use of a semiconductor switch in the current path enables a great reduction in a power loss during the current passage. The first switch 11 is higher in withstand voltage characteristics than the second switch 12, though lower in responsiveness to the electrode open control than the second switch 12. Conversely, the second switch 12 is lower in withstand voltage characteristics than the first switch, though higher in responsiveness to the electrode open control than the first switch 11. The series connection of the high-withstand voltage switch 11 with the low-withstand voltage switch 12 achieves a withstand voltage characteristics high enough as the direct-current interruption apparatus.

[0087] Further, owing to the inserted commutation element 21 in parallel with the second switch 12, the work of the commutation element 21 makes it possible to forcibly commutate the current quickly to the commutation element 21 according to the switch 12 with high responsiveness. When the first semiconductor switch 21b of the commutation element 21 is thereafter changed to OFF, it is possible this time to commutate the current of the first switch 11 quickly to the second semiconductor switch 22 as the current to be interrupted. Accordingly, it is possible to change the second semiconductor switch 22 to OFF before the value of the interruption target current commutated to the second semiconductor switch 22 increases very much. This enables to avoid an increase in size of the interruption apparatus.

[0088] Several embodiments of the present invention have been described hitherto, but 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 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.

REFERENCE SIGN LIST

[0089] 10, 10A, 10B, 10C...current path, 11...switch (high withstand voltage; first switch), 12...switch (low withstand voltage; second switch), 13...additional element, 14...interelectrode distance detecting unit, 15...interelectrode distance detecting unit, 16... current detecting unit, 17... current detecting unit, 21... commutation element, 21a...charge/discharge functional element, 21b...semiconductor switch (first semiconductor switch), 22...semiconductor switch (second semiconductor switch), 23...reactor, 24...nonlinear resistor, 31...current detecting unit, 40...control unit, 51...porcelain tube, 52...fixed-side plate electrode, 52a...fixed-side vertical magnetic field electrode, 53...movable-side plate electrode, 53a...movable-side vertical magnetic field electrode, 54...fixed-side current-carrying shaft, 55...movable-side current-carrying shaft, 56...bellows

Claims

1. A direct-current interruption apparatus comprising:
 - a current path including a first switch and a second switch connected in series, the first switch being a non-semiconductor device and having a first withstand voltage, the second switch being a non-semiconductor device and having a second withstand voltage lower than the first withstand voltage;

- a commutation element having one end connected with a connection node of the first switch and the second switch and including a functional element and a first semiconductor switch connected in series, the functional element having a charge/discharge function; 5
a second semiconductor switch being between and connected with the other end of the commutation element and one end of the first switch, the one end of the first switch being opposite to the other end of the first switch connected with the second switch; 10
a conductive path being between and connected with the other end of the commutation element and one end of the second switch, the one end of the second switch being opposite to the other end of the second switch connected with the first switch; and 15
a nonlinear resistor connected in parallel with the second semiconductor switch. 20
2. The direct-current interruption apparatus according to claim 1, wherein the first switch is a gas switch.
 3. The direct-current interruption apparatus according to claim 1, wherein the second switch is a vacuum switch having plate electrodes or vertical magnetic field electrodes. 25
 4. The direct-current interruption apparatus according to claim 1, further comprising a reactor inserted in series in the conductive path. 30
 5. The direct-current interruption apparatus according to claim 4, wherein the nonlinear resistor is connected in parallel with the connection in series of the second semiconductor switch and the reactor. 35
 6. The direct-current interruption apparatus according to claim 1, wherein the commutation element includes the functional element, the first semiconductor switch, and further a reactor connected in series. 40
 7. The direct-current interruption apparatus according to claim 1, further comprising an additional element connected in parallel with the second switch and configured to reduce the maximum voltage applied to the second switch. 45
 8. The direct-current interruption apparatus according to claim 7, wherein the additional element is one or more selected from the group consisting of a resistor, a nonlinear resistor, a capacitor, and a connection in series of a capacitor and a resistor. 50
 9. The direct-current interruption apparatus according to claim 1, further comprising: 55
 - a first control unit connected with the first switch and configured to control opening and closing of electrodes of the first switch;
 - a second control unit connected with the second switch and configured to control opening and closing of electrodes of the second switch;
 - a third control unit connected with the commutation element and the first and second control units, the third control unit being configured to control ON/OFF of the first semiconductor switch of the commutation element, and configured to control charging the functional element of the commutation element in advance and to control discharging the functional element at a predetermined timing; and
 - a fourth control unit connected with the second semiconductor switch and the third control unit and configured to control ON/OFF of the second semiconductor switch, wherein:
 - the third control unit is configured to control charging the functional element before the first control unit starts the electrode open control over the first switch and the second control unit starts the electrode open control over the second switch, configured to control discharging the functional element after the first control unit starts the electrode open control over the first switch and the second control unit starts the electrode open control over the second switch, and configured to control changing the first semiconductor switch to OFF after controlling the discharge; and
 - the fourth control unit is configured to control changing the second semiconductor switch to OFF after the third control unit controls changing the first semiconductor switch to OFF.
 10. The direct-current interruption apparatus according to claim 9, wherein the third control unit control charging the functional element of the commutation element after the first control unit starts the electrode open control over the first switch and the second control unit starts the electrode open control over the second switch and after an interelectrode distance of the second switch is assumed to reach a predetermined distance.
 11. The direct-current interruption apparatus according to claim 9, wherein the third control unit controls changing the first semiconductor switch to OFF after the third control unit control discharging the functional element and after a current flowing in the second switch is assumed to reach zero.
 12. The direct-current interruption apparatus according

to claim 9, wherein the fourth control unit controls changing the second semiconductor switch to OFF after the third control unit controls changing the first semiconductor switch to OFF and after an interelectrode distance of the first switch is assumed to reach a predetermined distance.

13. The direct-current interruption apparatus according to claim 9, further comprising a distance detecting unit provided to the second switch and configured to detect an interelectrode distance of the second switch to notify the detected interelectrode distance to the third control unit, wherein the third control unit controls discharging the functional element after the first control unit starts the electrode open control over the first switch and the second control unit starts the electrode open control over the second switch and after the distance detecting unit detects that the interelectrode distance of the second switch reaches a predetermined distance.
14. The direct-current interruption apparatus according to claim 9, further comprising a current detecting unit connected in series with the second switch and configured to detect a current flowing in the second switch to notify the detected current to the third control unit, wherein the third control unit controls changing the first semiconductor switch to OFF after the third control unit controls discharging the functional element and after the current detecting unit detects that the current flowing in the second switch reaches zero.
15. The direct-current interruption apparatus according to claim 9, further comprising a distance detecting unit provided to the first switch and configured to detect an interelectrode distance of the first switch to notify the detected interelectrode distance to the fourth control unit, wherein that the fourth control unit controls changing the second semiconductor switch to OFF after the third control unit controls changing the first semiconductor switch to OFF and after the distance detecting unit detects that the interelectrode distance of the first switch reaches a predetermined distance.
16. The direct-current interruption apparatus according to claim 9, further comprising a current detecting unit connected in series with the first switch and configured to detect a current flowing in the first switch to notify the detected current to the fourth control unit, wherein the fourth control unit controls changing the second semiconductor switch to OFF after the third control unit controls changing the first semiconductor switch to OFF and after the current detecting unit detects that the current flowing in the first switch reaches zero.

17. A direct-current interruption method with a direct-current interruption apparatus, the apparatus comprising:

a current path including a first switch and a second switch connected in series, the first switch being a non-semiconductor device and having a first withstand voltage, the second switch being a non-semiconductor device and having a second withstand voltage lower than the first withstand voltage;
a commutation element having one end connected with a connection node of the first switch and the second switch, and including a functional element and a first semiconductor switch connected in series, the functional element having a charge/discharge function;
a second semiconductor switch being between and connected with the other end of the commutation element and one end of the first switch, the one end of the first switch being opposite to the other end of the first switch connected with the second switch;
a conductive path being between and connected with the other end of the commutation element and one end of the second switch, the one end of the second switch being opposite to the other end of the second switch connected with the first switch; and
a nonlinear resistor connected in parallel with the second semiconductor switch,
the method comprising:

charging the functional element of the commutation element in advance;
discharging the functional element after starting electrode open control over the first switch and starting electrode open control over the second switch;
changing the first semiconductor switch to OFF after discharging the functional element; and
changing the second semiconductor switch to OFF after changing the first semiconductor switch to OFF.

FIG. 1

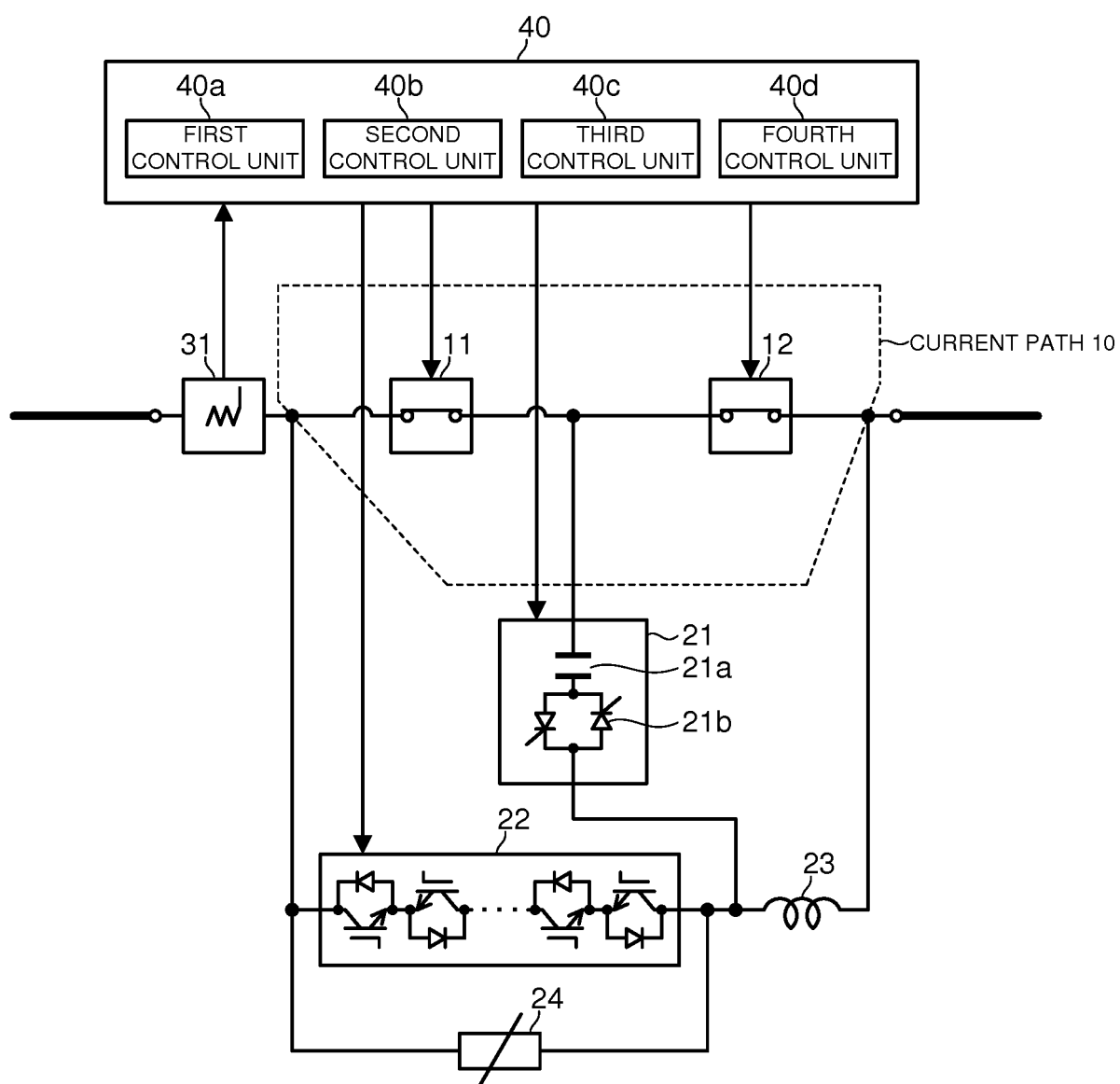


FIG. 2A

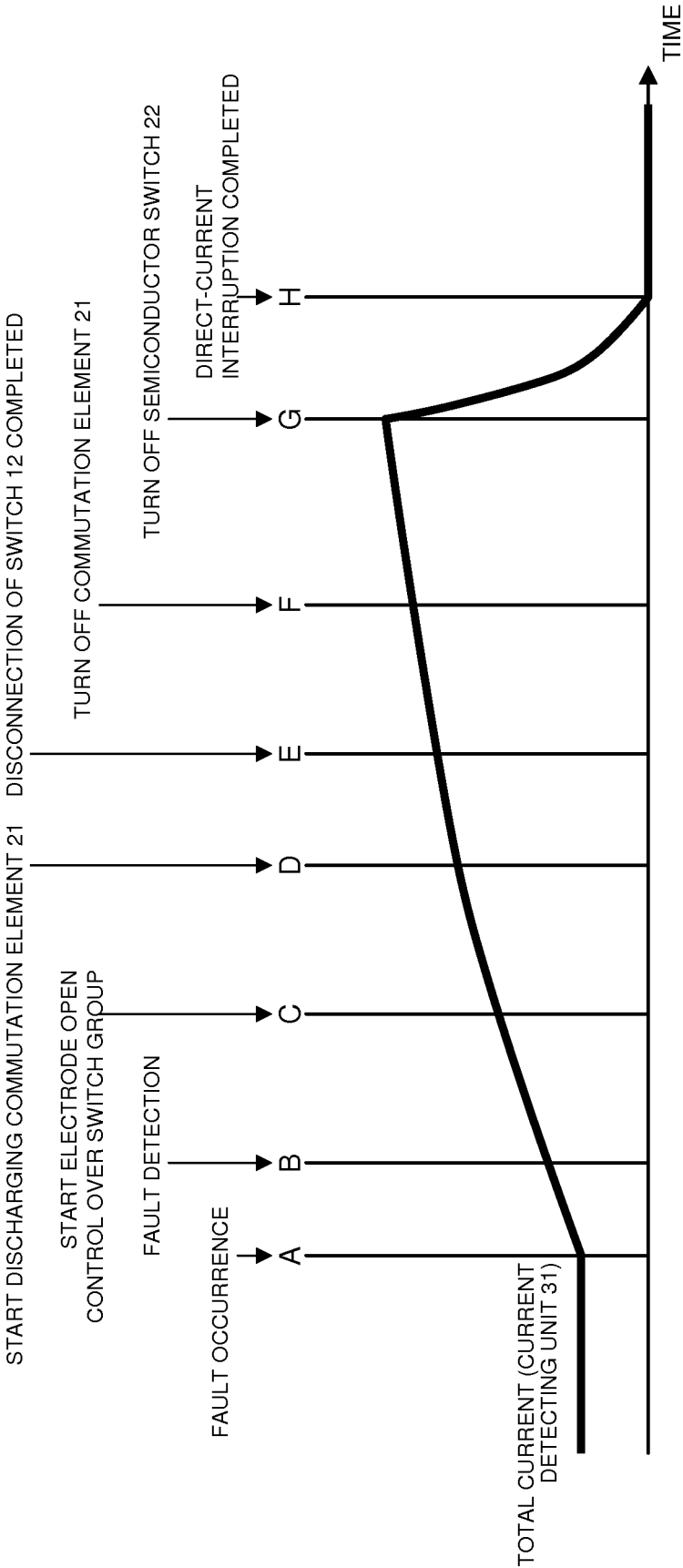


FIG. 2B

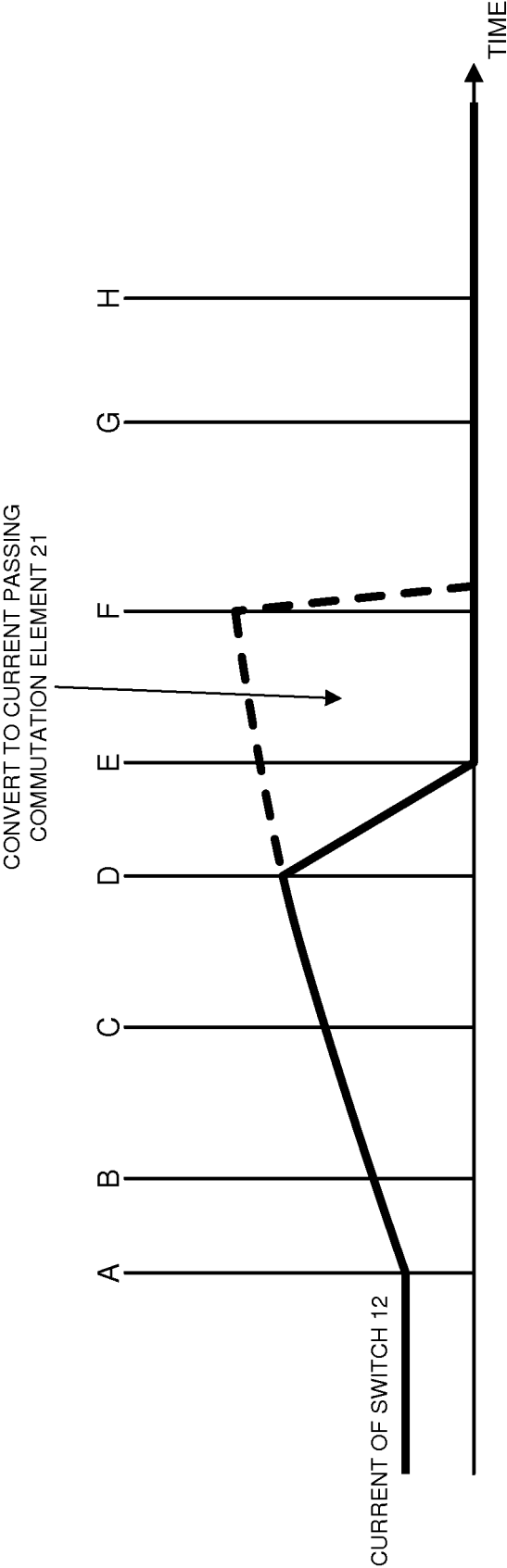


FIG. 2C

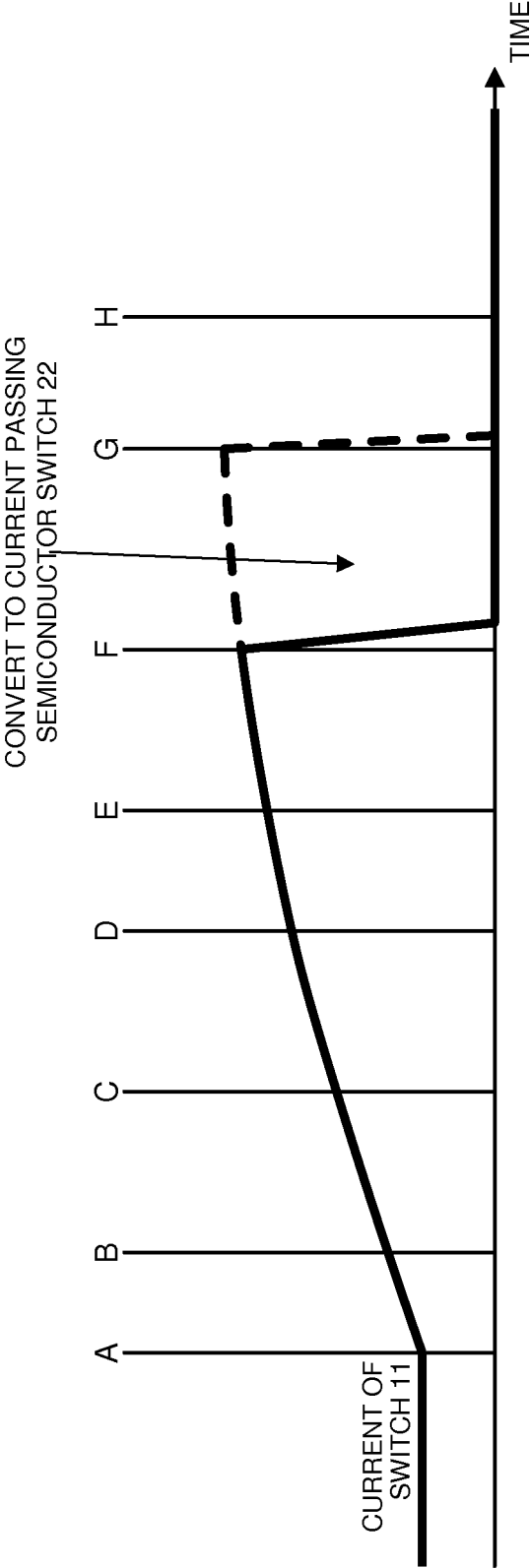


FIG. 2D

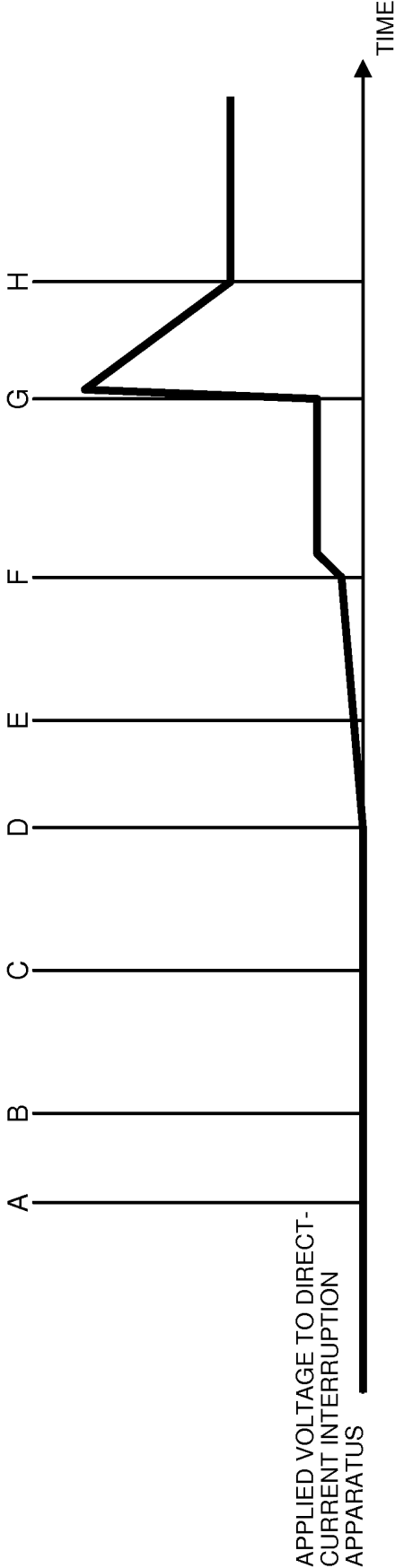


FIG. 3

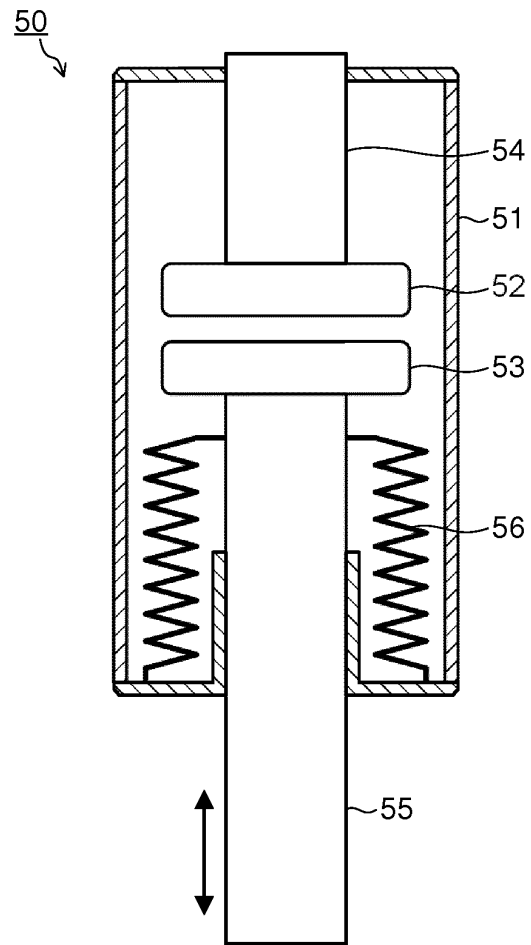


FIG. 4

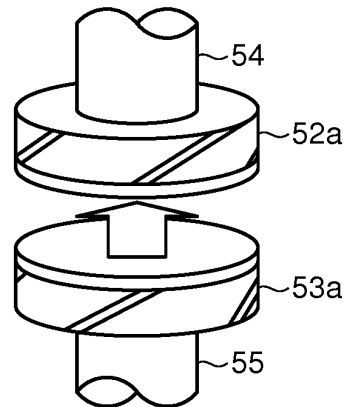


FIG. 5

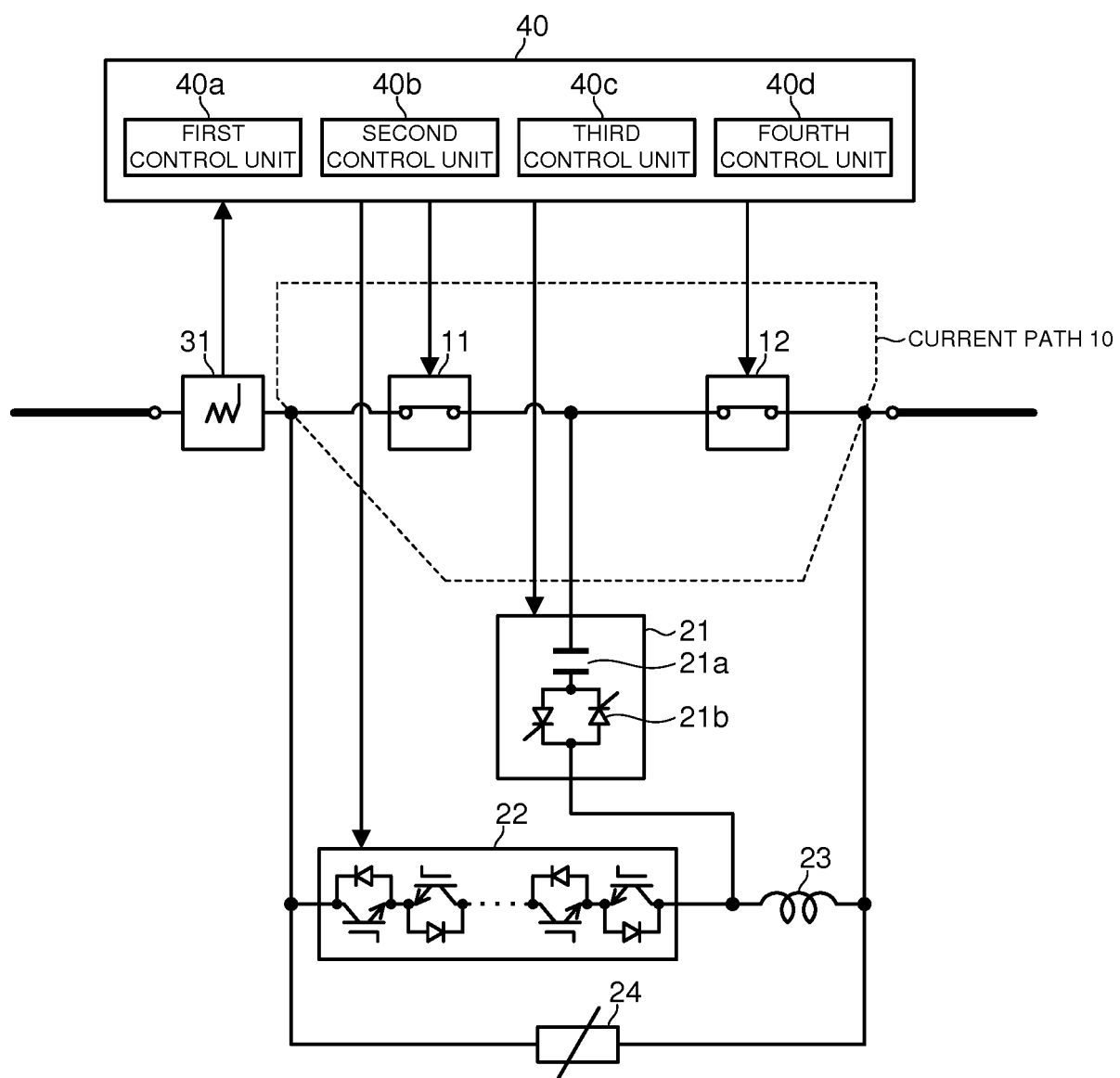


FIG. 6

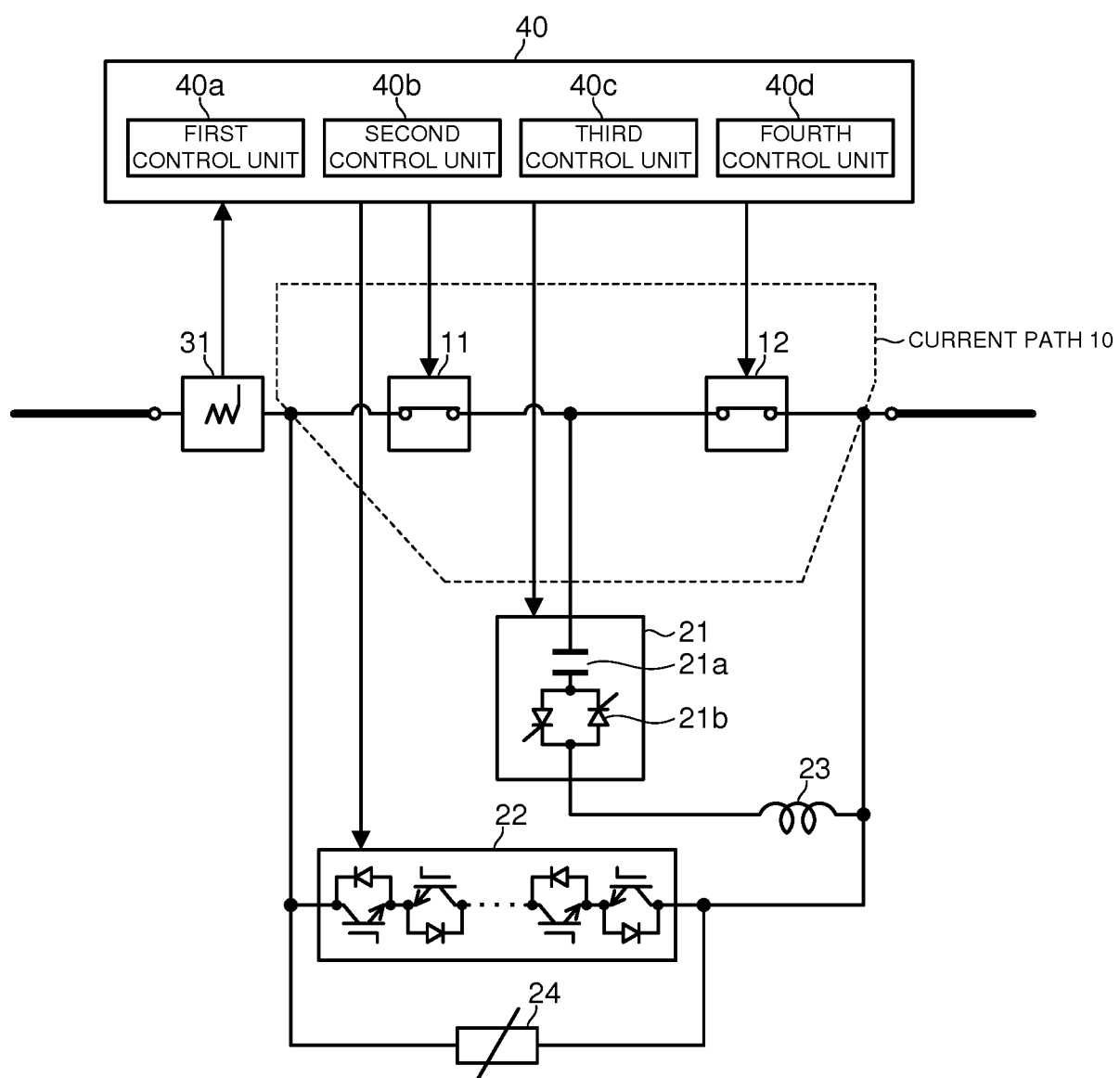


FIG. 7

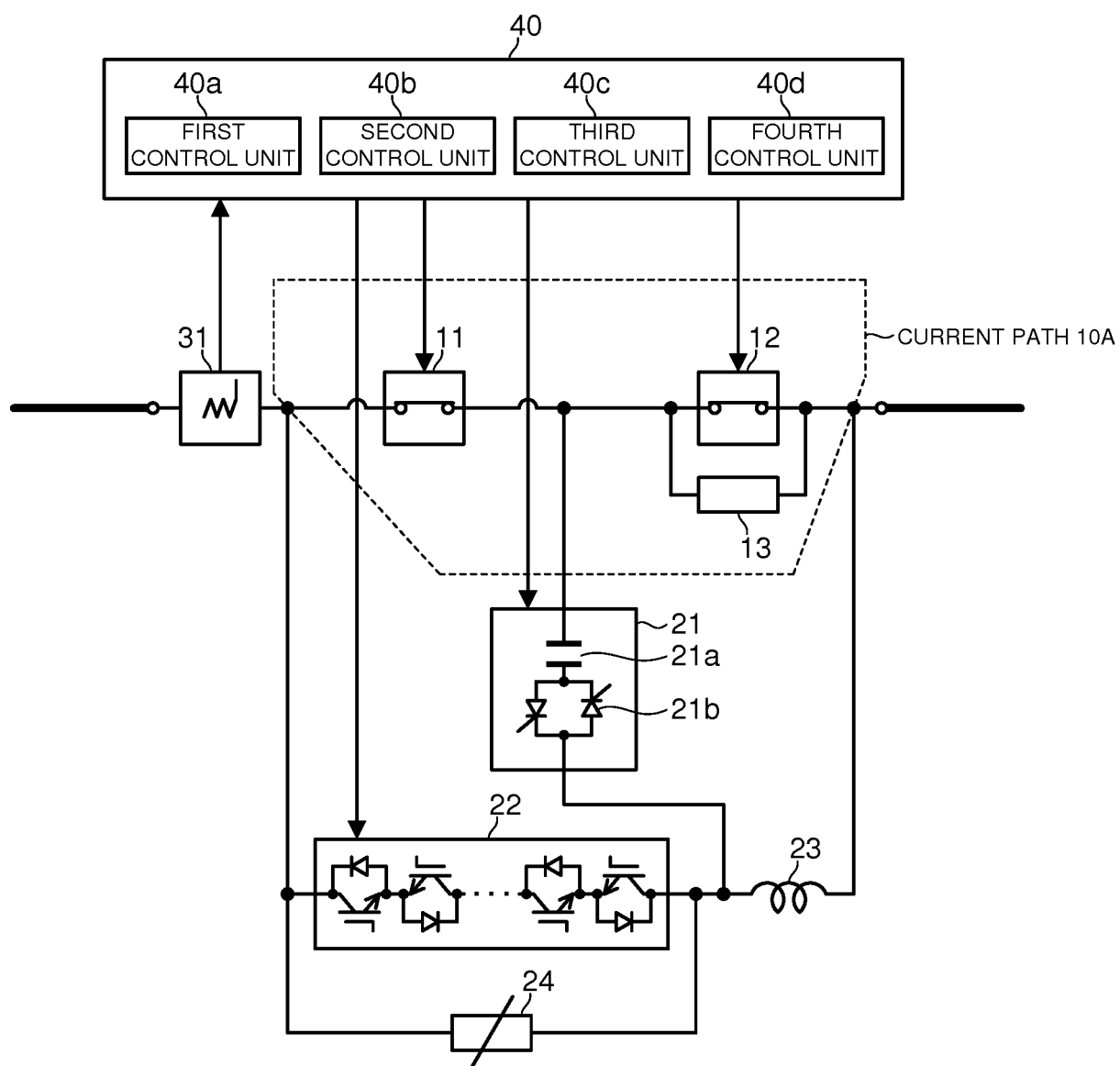


FIG. 8

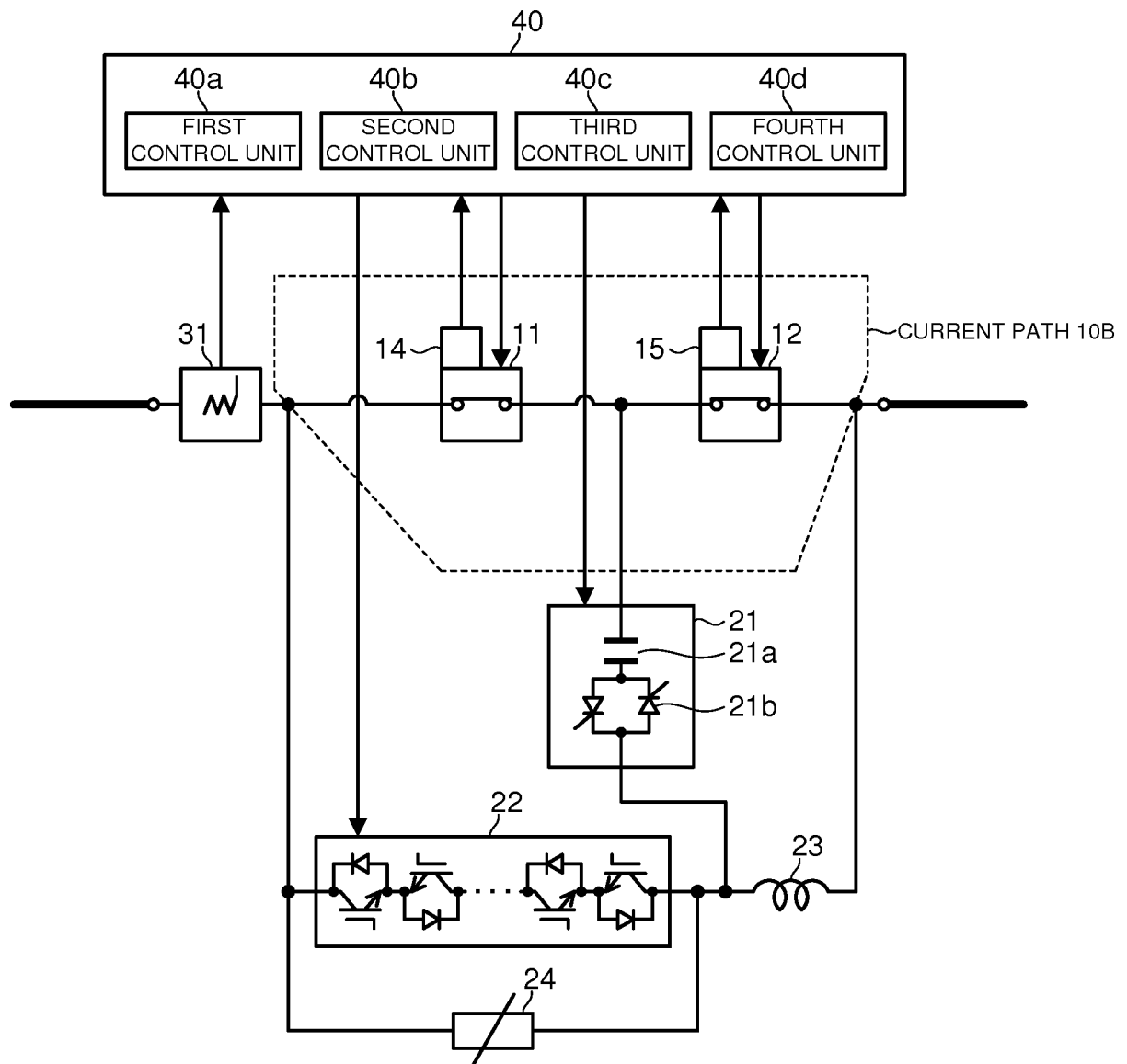


FIG. 9A

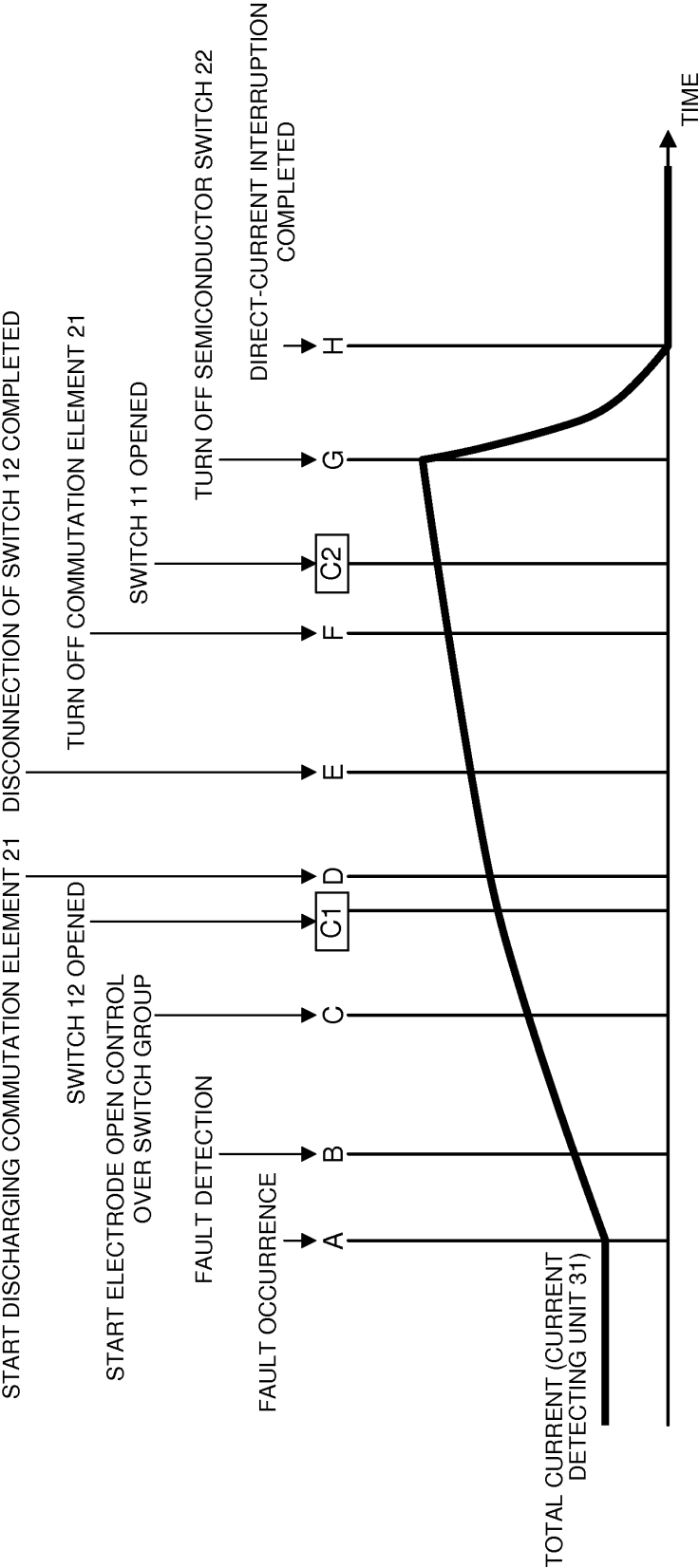


FIG. 9B

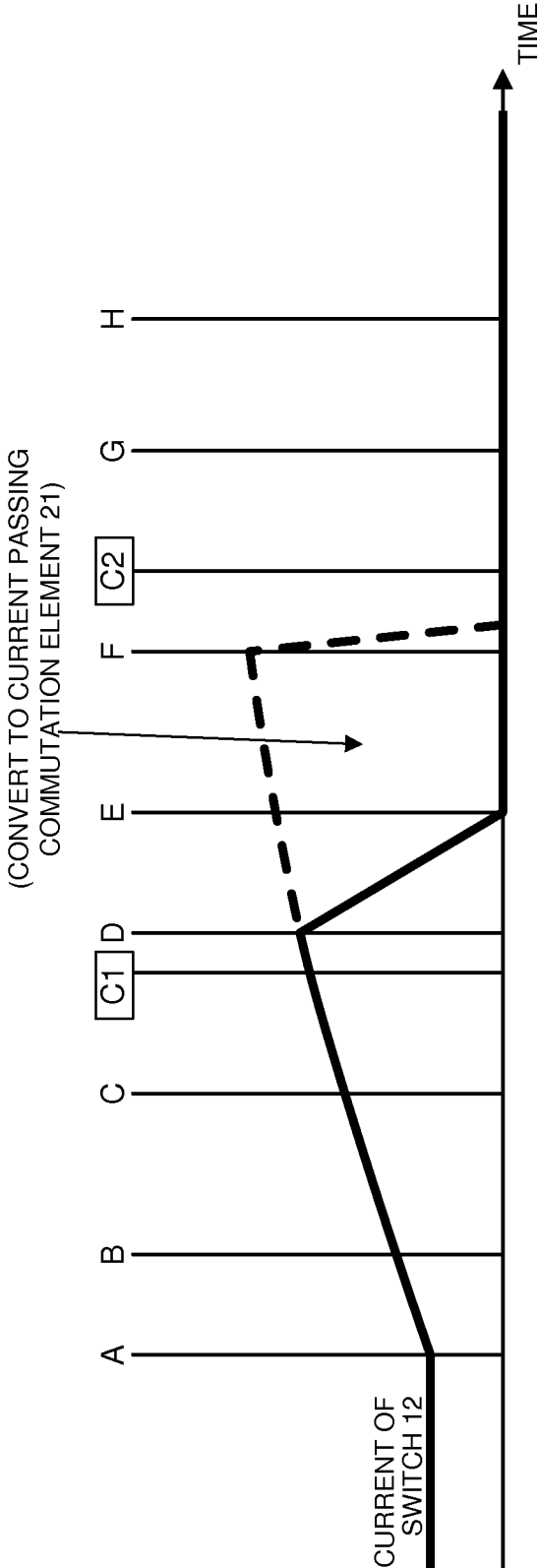


FIG. 9C

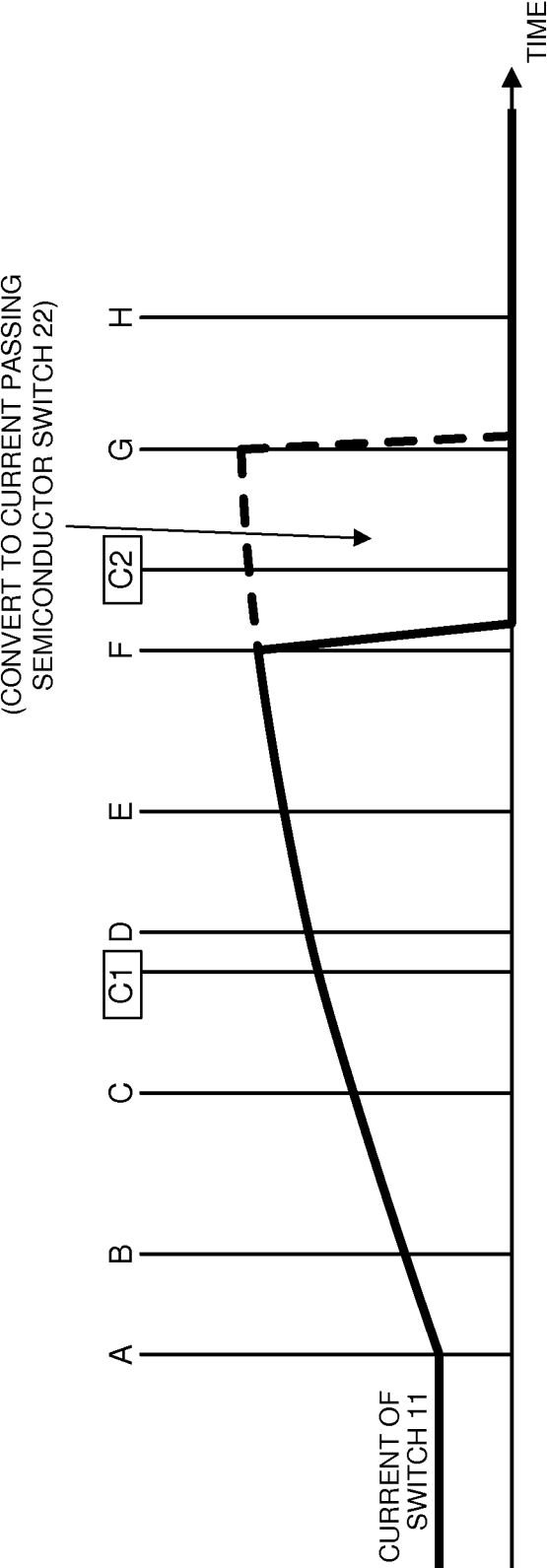


FIG. 9D

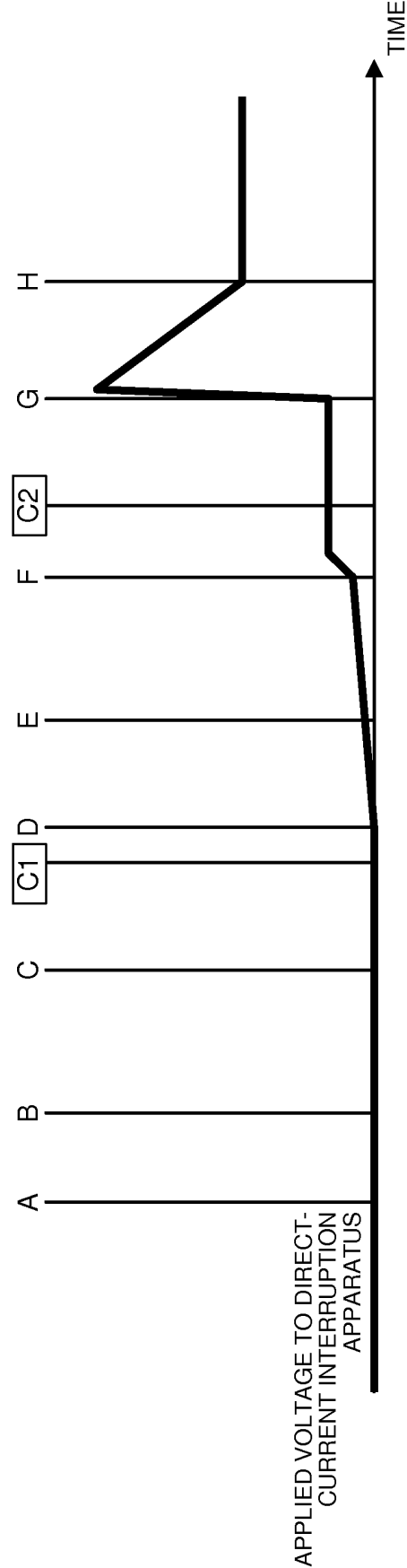


FIG. 10

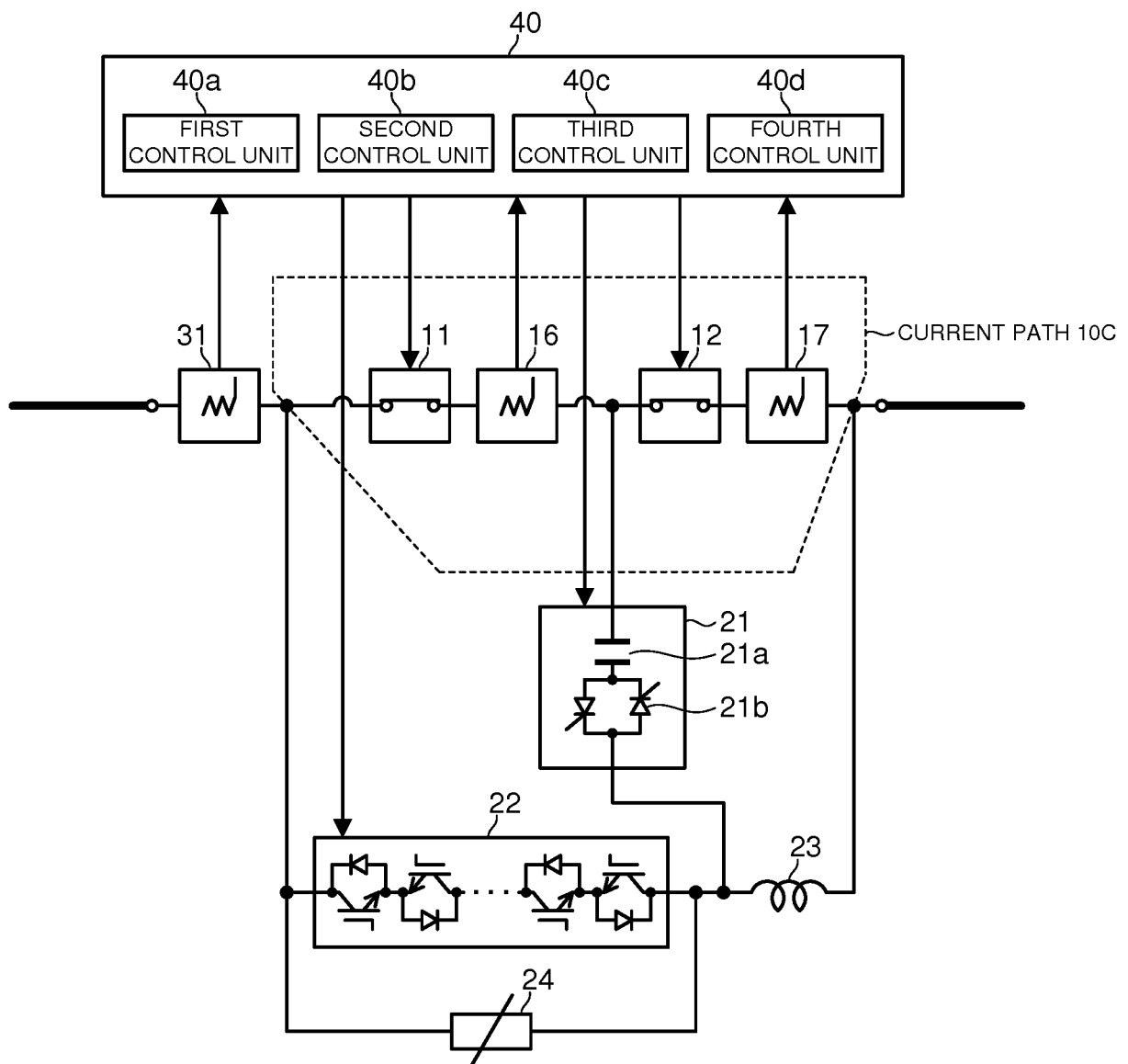


FIG. 11A

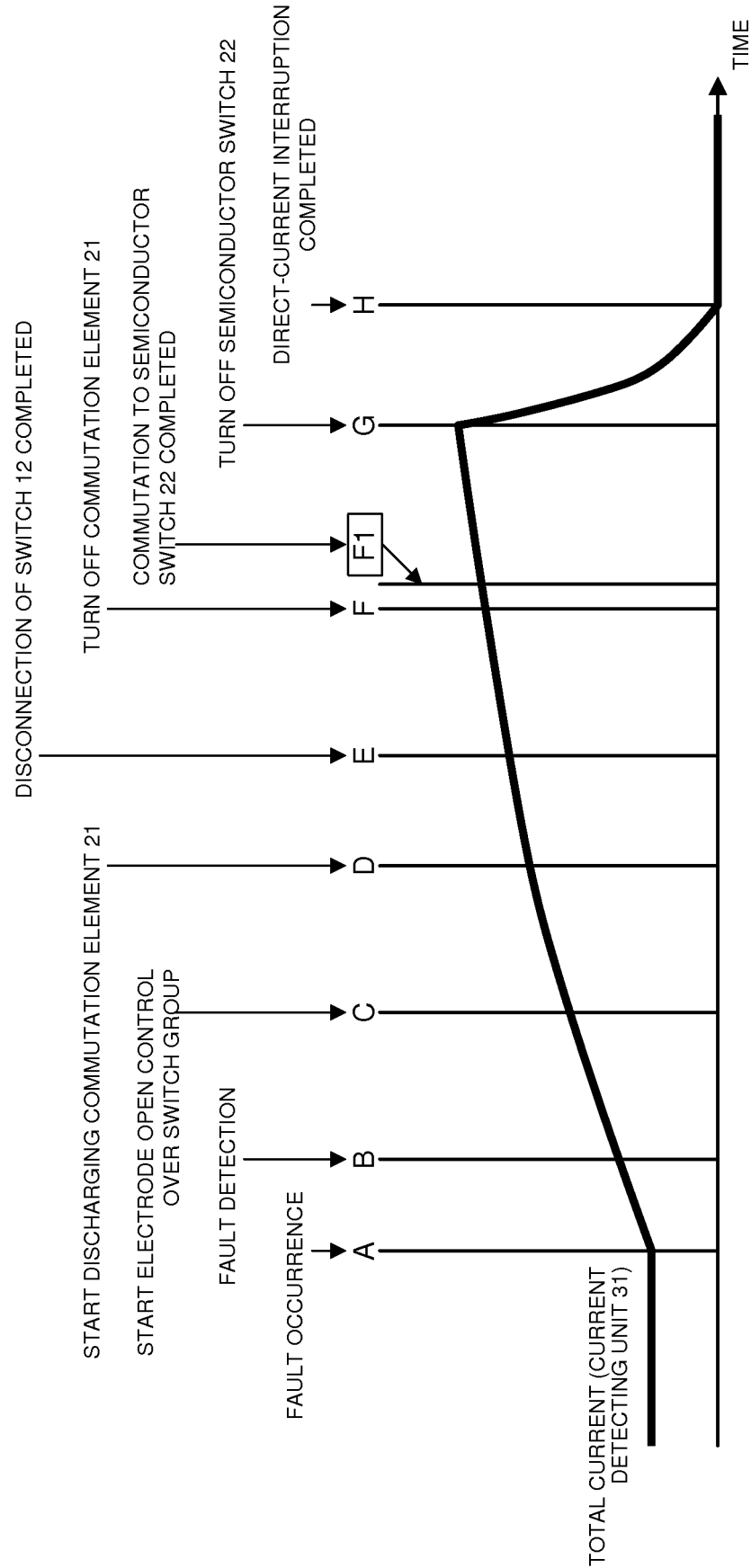


FIG. 11B

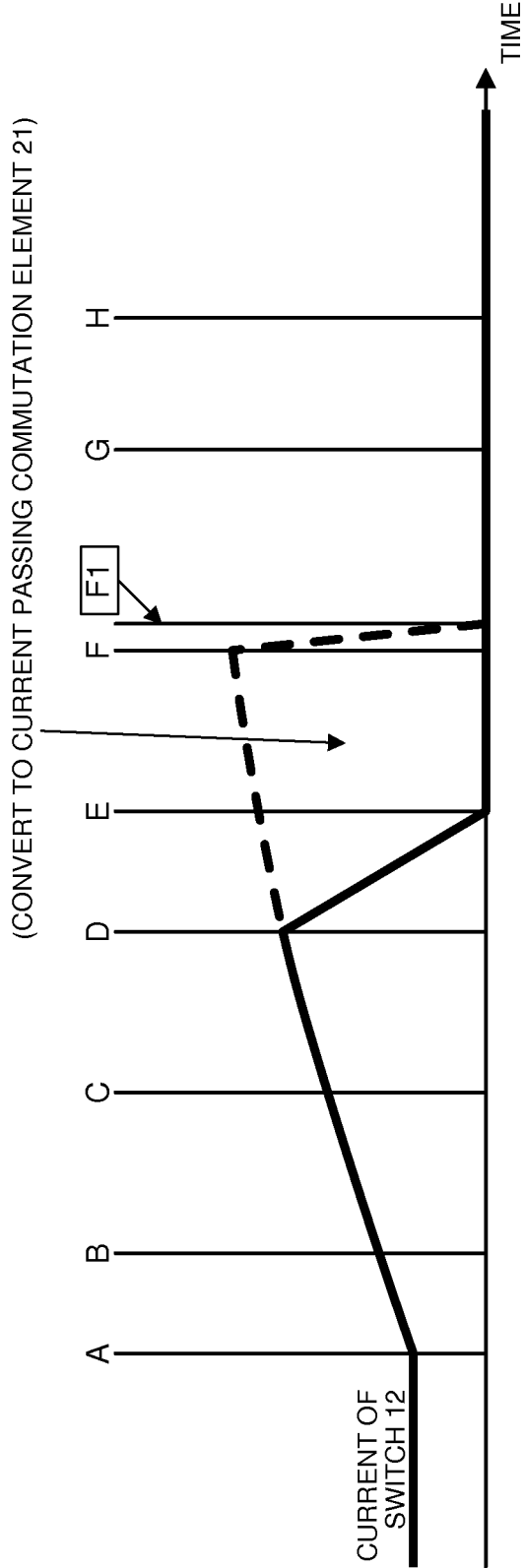


FIG. 11C

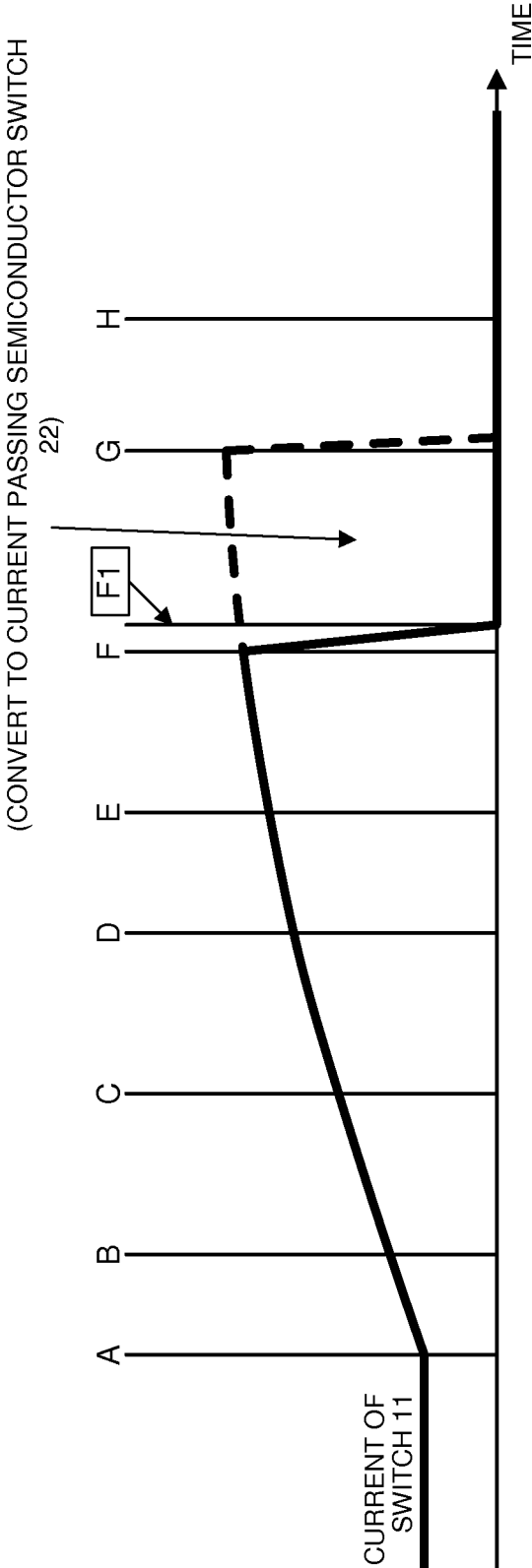
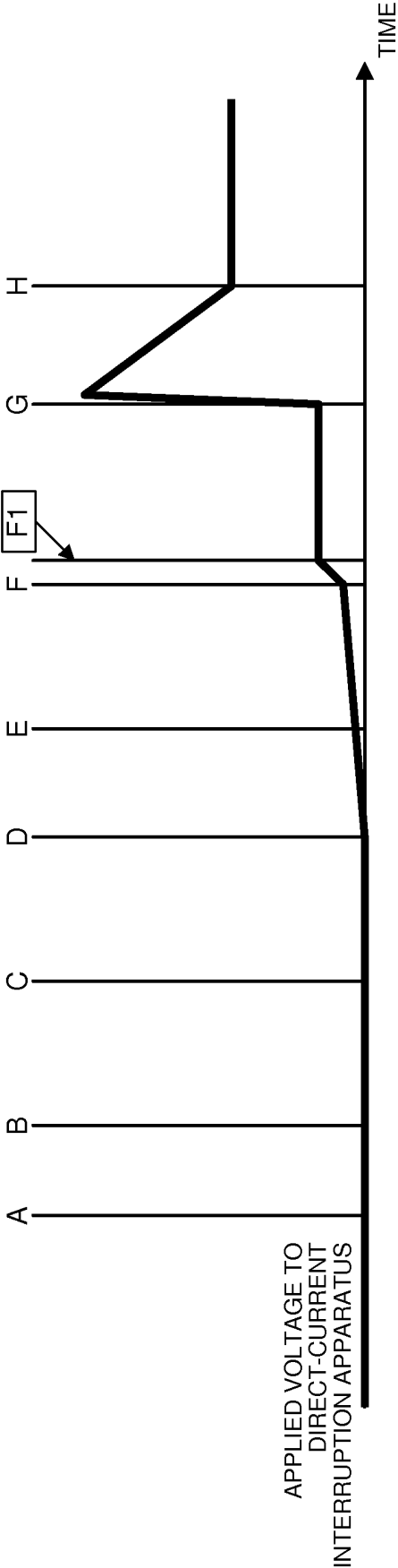


FIG. 11D



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/002782

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	JP 2015-079699 A (Toshiba Corp.), 23 April 2015 (23.04.2015), paragraphs [0010] to [0021]; fig. 1 (Family: none)	1-17
A	WO 2014/053554 A1 (ABB TECHNOLOGY AG), 10 April 2014 (10.04.2014), page 1, line 26 to page 2, line 14; page 5, lines 1 to 33; fig. 1 to 2 & JP 2015-534235 A & US 2015/0214724 A1 paragraphs [0005] to [0010], [0033] to [0038]; fig. 1 to 2 & EP 2904626 A1 & CN 104685597 A	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

02 September 2016 (02.09.16)

Date of mailing of the international search report

13 September 2016 (13.09.16)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/002782

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 6-076681 A (The Tokyo Electric Power Co., Inc., Toshiba Corp.), 18 March 1994 (18.03.1994), paragraphs [0013] to [0027]; fig. 1 to 3 (Family: none)	1-17
A	JP 60-194824 A (Mitsubishi Electric Corp.), 03 October 1985 (03.10.1985), page 1, lower right column to page 4, upper right column; fig. 1 to 6 (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. *The electric power system of the future - Integrating supergrids and microgrids, International Symposium in Bologna, Italy, 13 September 2011* **[0005]**
- **PER SKARBY ; UELI STEIGER.** An Ultra-fast Disconnecting Switch for a Hybrid HVDC Breaker - a technical breakthrough. *Ciger, Canada conference, Calgary, Canada, 09 September 2011* **[0005]**