



(11)

EP 4 095 877 A1

(12)

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

(43) Date of publication:
30.11.2022 Bulletin 2022/48

(51) International Patent Classification (IPC):
H01H 33/59 (2006.01)

(21) Application number: **20916137.1**

(52) Cooperative Patent Classification (CPC):
H01H 33/59

(22) Date of filing: **21.01.2020**

(86) International application number:
PCT/JP2020/001965

(87) International publication number:
WO 2021/149158 (29.07.2021 Gazette 2021/30)

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

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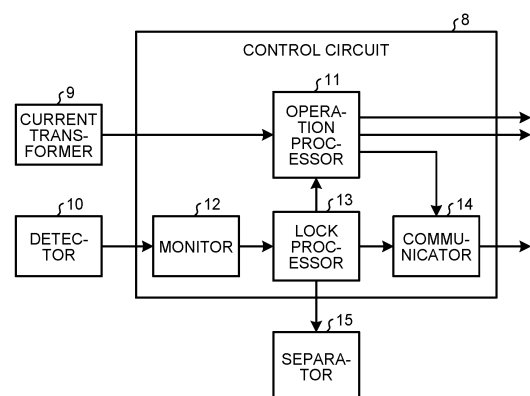
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(54) **DC CIRCUIT BREAKER**

(57) A direct-current circuit breaker includes a circuit breaker that interrupts a direct current flowing through a direct-current line. The direct-current circuit breaker includes: a resonant circuit including a capacitor, a reactor, and a switch connected in series to each other; a lightning arrester including a plurality of columns each including a stack of a plurality of nonlinear resistive elements, the lightning arrester being connected in parallel to the capacitor; an operation processor (11) that controls an opening operation and a closing operation by each of the circuit breaker and the switch; a monitor (12) that monitors the presence or absence of an anomaly in each of the plurality of columns; and a lock processor (13) that locks operations of the circuit breaker and the switch controlled by the operation processor (11) in a case where there is an anomaly in at least one or some columns out of the plurality of columns.

FIG.6



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Description

Field

[0001] The present disclosure relates to a direct-current circuit breaker including a lightning arrester.

Background

[0002] A direct-current circuit breaker forms a current zero point by superimposing an oscillating current on a direct current, and interrupts the direct current at the current zero point. As the direct-current circuit breaker, a direct-current circuit breaker of a forced-extinction type is known which includes a resonance circuit including a capacitor and a reactor and performs extinction by superimposing a resonance current generated by discharge of the capacitor on a direct current.

[0003] Patent Literature 1 discloses a direct-current circuit breaker including a lightning arrester for suppressing an overvoltage of a capacitor when interrupting a direct current.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Patent Application Laid-open No. S59-163722

Summary

Technical Problem

[0005] In a direct-current circuit breaker provided in a power system for high voltage direct current (HVDC) power transmission, energy processed by a lightning arrester may reach MJ order. Therefore, a lightning arrester including a plurality of columns connected in parallel to each other is used in the direct-current circuit breaker. Each of the plurality of columns is a stack of a plurality of nonlinear resistive elements. In the lightning arrester, when an anomaly occurs in at least one or some of the columns, an elevated temperature of the column in which the anomaly has occurred may lead to a failure, which is a state where it is difficult to perform a normal energy process. The conventional direct-current circuit breaker disclosed in Patent Literature 1 cannot obviate a failure of the lightning arrester, which is a problem.

[0006] The present disclosure has been made in view of the above, and an object thereof is to obtain a direct-current circuit breaker capable of obviating a failure of a lightning arrester.

Solution to Problem

[0007] To solve the above problems and achieve the object a direct-current circuit breaker according to the

present disclosure includes a circuit breaker adapted to interrupt a direct current flowing through a direct-current line, the direct-current circuit breaker comprising: a resonant circuit including a capacitor, a reactor, and a switch connected in series to each other; a lightning arrester including a plurality of columns each including a stack of a plurality of nonlinear resistive elements, the lightning arrester being connected in parallel to the capacitor; an operation processor adapted to control an opening operation and a closing operation by each of the circuit breaker and the switch; a monitor adapted to monitor presence or absence of an anomaly in each of the plurality of columns; and a lock processor adapted to lock operations of the circuit breaker and the switch controlled by the operation processor in a case where there is an anomaly in at least one or some columns out of the plurality of columns.

Advantageous Effects of Invention

[0008] The direct-current circuit breaker according to the present disclosure achieves an effect that it is possible to obviate a failure of a lightning arrester.

Brief Description of Drawings

[0009]

FIG. 1 is a diagram illustrating a configuration of a direct-current circuit breaker according to a first embodiment.

FIG. 2 is a side view of a lightning arrester included in the direct-current circuit breaker according to the first embodiment.

FIG. 3 is a top view of the lightning arrester included in the direct-current circuit breaker according to the first embodiment.

FIG. 4 is a view illustrating a schematic configuration of a column constituting the lightning arrester illustrated in FIGS. 2 and 3.

FIG. 5 is a diagram for explaining a process of energy performed by the lightning arrester illustrated in FIGS. 2 and 3.

FIG. 6 is a block diagram illustrating a control circuit included in the direct-current circuit breaker according to the first embodiment.

FIG. 7 is a view for explaining an operation of the direct-current circuit breaker in a case where an anomaly has occurred in one or some of a plurality of columns constituting the lightning arrester illustrated in FIGS. 2 and 3.

FIG. 8 is a flowchart illustrating an operation procedure of the direct-current circuit breaker according to the first embodiment.

FIG. 9 is a view for explaining an operation by the direct-current circuit breaker according to a second embodiment.

FIG. 10 is a flowchart illustrating an operation pro-

cedure of the direct-current circuit breaker according to the second embodiment.

FIG. 11 is a first diagram illustrating an example of a hardware configuration of the control circuit included in the direct-current circuit breaker according to the first or second embodiment.

FIG. 12 is a second diagram illustrating an example of the hardware configuration of the control circuit included in the direct-current circuit breaker according to the first or second embodiment.

Description of Embodiments

[0010] Hereinafter, a direct-current circuit breaker according to each embodiment will be described in detail with reference to the drawings. The present disclosure is not limited to the embodiments.

First Embodiment.

[0011] FIG. 1 is a diagram illustrating a configuration of a direct-current circuit breaker according to a first embodiment. A direct-current circuit breaker 1 according to the first embodiment is a mechanical direct-current circuit breaker (DCCB) including mechanical components. The direct-current circuit breaker 1 is provided on a direct-current line 2 of a power system. In the first embodiment, the power system is a power system that performs HVDC power transmission. The direct-current circuit breaker 1 interrupts a direct current upon occurrence of an accident such as short-circuit or earth fault in the direct-current line 2, thereby protecting the power system. The direct-current circuit breaker 1 interrupts the direct current at a current zero point formed by superimposing an oscillating current on a direct current flowing through the direct-current line 2.

[0012] The direct-current circuit breaker 1 includes: a circuit breaker 3 provided on the direct-current line 2; a capacitor 4, a reactor 5 and a high-speed switch 6 that constitute a resonance circuit; a lightning arrester 7 for suppressing an overvoltage to a voltage level based on a withstand voltage specification of a DCCB; and a control circuit 8 that controls the entirety of the direct-current circuit breaker 1. The capacitor 4, the reactor 5, and the high-speed switch 6 are connected in series to each other. The capacitor 4, the reactor 5, and the high-speed switch 6 are connected in parallel to the circuit breaker 3. The lightning arrester 7 is connected in parallel with the capacitor 4 and the high-speed switch 6.

[0013] At the above-described current zero point formed by the oscillating current and the direct current canceling each other, the circuit breaker 3 interrupts the direct current. That is, the circuit breaker 3 interrupts the direct current by forced extinction. The circuit breaker 3 is a circuit breaker capable of performing high-speed current interruption, and is, for example, a vacuum circuit breaker (VCB). The capacitor 4 and the reactor 5 generate an oscillating current by discharging of the capacitor

4. The high-speed switch 6 is a switch that performs closing for forming a current zero point.

[0014] The direct-current line 2 includes a current transformer 9 that detects an accident current which is a direct-current flowing when an accident occurs. The current transformer 9 outputs a detection result of the accident current to the control circuit 8. A device other than the current transformer 9 may be used as the device that detects the accident current. The control circuit 8 outputs a command for an opening operation and a command for a closing operation to each of the circuit breaker 3 and the high-speed switch 6. The control circuit 8 sends a signal indicating conditions of the direct-current circuit breaker 1 to a control panel which is a device outside the direct-current circuit breaker 1. The control panel is not illustrated. The destination of the signal transmitted from the control circuit 8 may be a device other than the control panel.

[0015] When in a steady state, i.e., when the power system is in a steady state, the circuit breaker 3 is closed and the high-speed switch 6 is open. The capacitor 4 is charged by a direct-current voltage in the steady state, an external power supply, or the like. When an accident occurs, the circuit breaker 3 performs the opening operation and the high-speed switch 6 performs the closing operation. When the high-speed switch 6 is closed, electric charges from the capacitor 4 are discharged to a loop including the high-speed switch 6, the capacitor 4, the reactor 5, and the circuit breaker 3. When the electric charges are discharged from the capacitor 4, an oscillating current that passes through the reactor 5, the circuit breaker 3, and the high-speed switch 6 flows from the capacitor 4. As a result, the direct-current circuit breaker 1 superimposes, on an accident current at the circuit breaker 3, the oscillating current in a direction opposite to the direction of the direct current, which is the accident current. When the current zero point is formed by superimposing the oscillating current on the accident current, the extinction of arc is completed in the circuit breaker 3 during the opening operation. The lightning arrester 7 suppresses an overvoltage generated after the extinction of arc by the circuit breaker 3.

[0016] Next, a configuration of the lightning arrester 7 will be described. FIG. 2 is a side view of the lightning arrester included in the direct-current circuit breaker according to the first embodiment. FIG. 3 is a top view of the lightning arrester included in the direct-current circuit breaker according to the first embodiment. The lightning arrester 7 includes a plurality of columns 20 arranged in an array in a horizontal direction. In the example illustrated in FIG. 3, the lightning arrester 7 includes 12 columns 20. As the number of columns 20 constituting the lightning arrester 7, any number thereof may be employed. The plurality of columns 20 are connected in parallel to each other.

[0017] An upper end of each of the plurality of columns 20 is attached to an upper plate 21. A lower end of each of the plurality of columns 20 is attached to a lower plate

22. The plurality of columns 20 in a state of being attached to the upper plate 21 and the lower plate 22 are supported by supports 23. Below the plurality of columns 20 supported by the supports 23, a space is provided which is capable of accommodating the column 20 separated from the upper plate 21 and the lower plate 22.

[0018] FIG. 4 is a view illustrating a schematic configuration of the column constituting the lightning arrester illustrated in FIGS. 2 and 3. The column 20 includes: a stack of a plurality of nonlinear resistive elements 24; a container 25 in which the stack is accommodated; an electrode 26 on a power supply side connected to an upper end of the stack; and an electrode 27 on a ground side connected to a lower end of the stack. The nonlinear resistive elements 24 are each a sintered body containing zinc oxide as a main component. The plurality of nonlinear resistive elements 24 constituting the stack are connected in series to each other. The container 25 is a container made of an insulating material, and is a porcelain hollow insulator or a polymer hollow insulator. FIG. 4 illustrates a cross section through each of the plurality of nonlinear resistive elements 24 of the column 20.

[0019] FIG. 5 is a diagram for explaining a process of energy performed by the lightning arrester illustrated in FIGS. 2 and 3. Current I_{CB} is a current flowing through the circuit breaker 3. Voltage V_{CB} is a voltage applied to the circuit breaker 3. Energy E is energy processed by the lightning arrester 7. In FIG. 5, respective changes in current I_{CB} , voltage V_{CB} , and energy E after the occurrence of an accident are indicated by graphs. In the graph of current I_{CB} , a broken line indicates a current waveform in a case where the circuit breaker 3 is assumed to be in a closed state. Such a current waveform is a current waveform obtained by combining a direct current and a resonance current.

[0020] After the occurrence of the accident at time t_1 , an accident current larger than a current in the steady state flows through the direct-current line 2, and thereby current I_{CB} increases. The circuit breaker 3 performs the opening operation at any time between time t_1 and time t_2 . At time t_2 , the high-speed switch 6 performs the closing operation. The direct-current circuit breaker 1 forms a current zero point by superimposing, on the accident current, an oscillating current generated in the resonance circuit by the high-speed switch 6 being closed. As a result, the direct-current circuit breaker 1 forcibly interrupts the accident current.

[0021] By forcibly interrupting the accident current, electromagnetic energy remains in the system, the electromagnetic energy being expressed as $1/2 \times LI^2$ where L denotes inductance and I denotes current. The lightning arrester 7 starts processing energy from time t_3 when voltage V_{CB} has risen to a certain voltage value. The lightning arrester 7 processes energy from time t_3 to time t_4 , and thereby the lightning arrester 7 suppresses an increase in voltage V_{CB} .

[0022] The lightning arrester 7 is designed such that a current uniformly flows to each column 20 in a period in

which energy is processed. However, currents flowing through the columns 20 may vary due to a difference in characteristics such as impedance unique to each column 20. As the number of columns 20 constituting the lightning arrester 7 increases, there is a higher possibility that the column 20 in which a magnitude of a current flowing therethrough is different from magnitudes of currents flowing through other columns 20 is included in the plurality of columns 20. Therefore, as the number of columns 20 increases, there is a higher probability that the variation in the currents flowing through the columns 20 increases.

[0023] When the currents flowing through the plurality of columns 20 become nonuniform, a temperature in the column 20 through which a large current flows rises to be higher than temperatures in other columns 20. If a current is continued to be concentrated on one or some of the columns 20, an anomaly that temperatures of the columns 20 exceed an allowable temperature may lead to a failure of the lightning arrester 7. Here, the allowable temperature is a maximum value of a temperature at which the column 20 can maintain a state in which energy is normally processed.

[0024] In the first embodiment, the direct-current circuit breaker 1 monitors an anomaly in each of the plurality of columns 20 by measuring a temperature in each of the plurality of columns 20. When an anomaly occurs in one or some columns 20 out of the plurality of columns 20, the direct-current circuit breaker 1 locks the operations of the circuit breaker 3 and the high-speed switch 6, and thereby the direct-current circuit breaker 1 is stopped operating. In addition, the direct-current circuit breaker 1 physically separates the column 20 in which the anomaly has occurred from other columns 20. As a result, the direct-current circuit breaker 1 obviates a failure of the lightning arrester 7 in a case where an anomaly has occurred in one or some columns 20 out of the plurality of columns 20.

[0025] FIG. 6 is a block diagram illustrating the control circuit included in the direct-current circuit breaker according to the first embodiment. FIG. 6 illustrates components of the control circuit 8 and components connected to the control circuit 8. The direct-current circuit breaker 1 includes: a detector 10 that detects a temperature of each column 20 provided in the lightning arrester 7; and a separator 15. The separator 15 is a mechanism for separating one or some columns 20 in which an anomaly has occurred from other columns 20. In FIG. 1, illustrations of the detector 10 and the separator 15 are omitted.

[0026] The detector 10 includes, for example, a contact type temperature sensor attached to each of the plurality of columns 20. The temperature sensor is attached to the container 25. The detector 10 may be a non-contact type temperature sensor such as a radiation thermometer or an infrared thermography device.

[0027] The control circuit 8 includes: an operation processor 11 that controls an opening operation and a closing

operation by each of the circuit breaker 3 and the high-speed switch 6; a monitor 12 that monitors the presence or absence of an anomaly in each of the plurality of columns 20; and a lock processor 13 that locks the operations of the circuit breaker 3 and the high-speed switch 6 controlled by the operation processor 11 in a case where an anomaly has occurred in at least one or some columns 20 out of the plurality of columns 20. In the first embodiment, the monitor 12 determines that an anomaly has occurred in one or some columns 20 having a temperature rise exceeding the allowable temperature out of the plurality of columns 20. The control circuit 8 further includes a communicator 14 that communicates with a device outside the direct-current circuit breaker 1.

[0028] The detection result of the accident current obtained by the current transformer 9 is input to the operation processor 11. When a current exceeding a threshold which is a criterion for determination of accident current is detected in the current transformer 9, the operation processor 11 outputs a command for an opening operation to the circuit breaker 3 and outputs a command for a closing operation to the high-speed switch 6. The operation processor 11 instructs the communicator 14 to notify that the operation for interruption has been performed. The communicator 14 transmits, to the control panel, a signal indicating that the direct-current circuit breaker 1 has performed the operation for interruption.

[0029] Detection results of temperatures obtained by the detector 10 are input to the monitor 12. The monitor 12 determines whether there is the column 20 of which temperature has exceeded a preset allowable temperature in the plurality of columns 20 on the basis of the detection result of the temperature of each column 20. In a case where there is the column 20 of which temperature has exceeded the allowable temperature, the monitor 12 determines that an anomaly has occurred in the column 20. When it is determined that there is the column 20 in which an anomaly has occurred, the monitor 12 outputs, to the lock processor 13, information indicating the column 20 in which the anomaly has occurred together with a determination result indicating that the anomaly has occurred.

[0030] When the determination result indicating that the anomaly has occurred is input from the monitor 12, the lock processor 13 outputs a command for locking the operations of the circuit breaker 3 and the high-speed switch 6 to the operation processor 11. The operation processor 11 stops the control of the circuit breaker 3 and the high-speed switch 6 in accordance with the command from the lock processor 13. The direct-current circuit breaker 1 locks the operation for interruption by maintaining the circuit breaker 3 in the closed state and maintaining the high-speed switch 6 in the open state until the lock by the lock processor 13 is unlocked. The lock processor 13 instructs the communicator 14 to notify that the direct-current circuit breaker 1 has locked the operation for interruption. The communicator 14 transmits, to the control panel, a signal indicating that the direct-current

circuit breaker 1 has locked the operation for interruption. While the direct-current circuit breaker 1 locks the operation for interruption, the power system is protected by a protection means other than the direct-current circuit breaker 1.

[0031] The lock processor 13 outputs information indicating the column 20 in which the anomaly has occurred to the separator 15. The separator 15 separates the column 20 in which the anomaly has occurred from other columns 20 on the basis of the information from the lock processor 13.

[0032] FIG. 7 is a view for explaining an operation of the direct-current circuit breaker in a case where an anomaly has occurred in one or some of the plurality of columns constituting the lightning arrester illustrated in FIGS. 2 and 3. In the example illustrated in FIG. 7, it is assumed that an anomaly has occurred in a column 20a which is one of the plurality of columns 20.

[0033] With respect to the column 20a in which the anomaly has occurred, the separator 15 detaches an upper end of the column 20a from the upper plate 21 and detaches a lower end of the column 20a from the lower plate 22. When the column 20a is detached from the upper plate 21 and the lower plate 22, the column 20a drops downward by gravity. The column 20a in which the anomaly has occurred drops downward, thereby being physically separated from other columns 20. The column 20a is electrically insulated from other columns 20 by being physically separated from other columns 20. The method of separating the column 20a from other columns 20 by the separator 15 is not limited to the method described in the first embodiment. The separator 15 may separate the column 20a from other columns 20 by a method other than the method in which the column 20a is dropped.

[0034] The monitor 12 continues to acquire the detection result of the temperature of each column 20 other than the column 20a thus separated. The monitor 12 determines whether the temperature of each column 20 other than the column 20a out of the plurality of columns 20 has decreased to a reference temperature. The reference temperature is a temperature set in advance as a reference for restart of the operation by the direct-current circuit breaker 1. The lock processor 13 unlocks the operations of the circuit breaker 3 and the high-speed switch 6 in a case where the temperature of each column 20 has decreased to the reference temperature.

[0035] After the column 20a is separated from other columns 20, the column 20a is collected by an operator. The lightning arrester 7 is replenished with a new column 20, which is a substitute for the column 20a in which the anomaly has occurred, by the operator. The direct-current circuit breaker 1 may include a mechanism for making replenishment of the new column 20. In that case, the replenishment of the new column 20 is automatically performed by the mechanism regardless of the operator. The lock processor 13 may unlock the lock after it is confirmed that the temperature of each column 20 has decreased to the reference temperature and after the re-

plenishment of the column 20 has been performed. The lock processor 13 may unlock the lock when it is confirmed that the temperature of each column 20 has decreased to the reference temperature regardless whether the replenishment of the column 20 has been performed or not.

[0036] FIG. 8 is a flowchart illustrating an operation procedure of the direct-current circuit breaker according to the first embodiment. In step S1, the detector 10 measures the temperature of each column 20 constituting the lightning arrester 7. In step S2, the monitor 12 determines whether there is the column 20 of which temperature has exceeded the allowable temperature. If there is no column 20 of which temperature has exceeded the allowable temperature (step S2, No), the direct-current circuit breaker 1 returns the procedure to step S1.

[0037] If there is the column 20 of which temperature has exceeded the allowable temperature (step S2, Yes), in step S3, the lock processor 13 locks the operations of the circuit breaker 3 and the high-speed switch 6 controlled by the operation processor 11. That is, the lock processor 13 locks the operation for interruption by the direct-current circuit breaker 1. In step S4, the separator 15 separates the column 20 in which the anomaly has occurred.

[0038] In step S5, the monitor 12 determines whether the temperature of each column 20 other than the column 20 in which the anomaly has occurred is equal to or lower than the reference temperature. If the temperature of each column 20 is not equal to or lower than the reference temperature (step S5, No), the direct-current circuit breaker 1 returns the procedure to step S5. If the temperature of each column 20 is equal to or lower than the reference temperature (step S5, Yes), in step S6, the lock processor 13 unlocks the operation for interruption by the direct-current circuit breaker 1. As a result, the direct-current circuit breaker 1 terminates the operation in accordance with the procedure illustrated in FIG. 8.

[0039] Note that the monitor 12 is not limited to those monitoring the presence or absence of an anomaly on the basis of a temperature detected by the detector 10. The monitor 12 may monitor the presence or absence of an anomaly on the basis of a detection result of a current flowing through each of the plurality of columns 20. In that case, as the detector 10, an ammeter that detects a current flowing through each of the plurality of columns 20 is used. For each column 20, the monitor 12 calculates a difference between a current flowing through the column 20 and a current flowing through another column 20. The monitor 12 determines that an anomaly that a current is concentrated has occurred in the column 20 in which the calculated difference is larger than a threshold set in advance.

[0040] The direct-current circuit breaker 1 according to the first embodiment is not limited to a mechanical direct-current circuit breaker. The direct-current circuit breaker 1 may be a hybrid direct-current circuit breaker constituted by combining a mechanical component and

a semiconductor component.

[0041] According to the first embodiment, the direct-current circuit breaker 1 includes: the monitor 12 that monitors the presence or absence of an anomaly in each of the plurality of columns 20; and the lock processor 13 that locks the operations of the circuit breaker 3 and the high-speed switch 6 controlled by the operation processor 11. The monitor 12 determines that an anomaly has occurred in one or some columns 20 having a temperature rise exceeding the allowable temperature out of the plurality of columns 20. In a case where there is a temperature rise exceeding the allowable temperature due to current concentration in one or some columns 20, the direct-current circuit breaker 1 obviates a failure of the lightning arrester 7 by locking the operation for interruption. As a result, the direct-current circuit breaker 1 achieves an effect that it is possible to obviate a failure of the lightning arrester 7.

20 Second Embodiment.

[0042] FIG. 9 is a view for explaining an operation by the direct-current circuit breaker according to a second embodiment. The direct-current circuit breaker 1 according to the second embodiment has a configuration similar to that of the direct-current circuit breaker 1 according to the first embodiment. The direct-current circuit breaker 1 according to the second embodiment locks the operation for interruption in a case where there is an anomaly that an overall temperature of the plurality of columns 20 constituting the lightning arrester 7 rises. In the second embodiment, the same components as those in the first embodiment are denoted by the same reference numerals, and configurations different from those in the first embodiment will mainly be described.

[0043] In the direct-current circuit breaker 1, when a current uniformly flows through each of the plurality of columns 20, an overall temperature of the plurality of columns 20 may uniformly rise. As the number of columns 20 connected in parallel to each other in the lightning arrester 7 is increased with respect to energy assumed to be processed in the lightning arrester 7, the number of columns 20 through which a current flows increases, and thereby it is possible to reduce the rising of the overall temperature of the plurality of columns 20. However, while it is possible to reduce the rising of the overall temperature of the plurality of columns 20 by increasing the number of columns 20 to be larger than the number thereof required with respect to the energy assumed to be processed, the increase in the number of columns 20 provided in the lightning arrester 7 leads to an increase in size of the lightning arrester 7. In the second embodiment, when the overall temperature of the plurality of columns 20 rises, the direct-current circuit breaker 1 locks the operations of the circuit breaker 3 and the high-speed switch 6, and thereby the direct-current circuit breaker 1 is stopped operating. As a result, the direct-current circuit breaker 1 obviates a failure of the lightning

arrester 7 due to the rising of the overall temperature of the plurality of columns 20. In addition, the direct-current circuit breaker 1 may not increase the number of columns 20 to be larger than the number thereof required with respect to the energy assumed to be processed.

[0044] The monitor 12 determines whether the overall temperature of the plurality of columns 20 has risen to a first reference temperature on the basis of the detection result of the temperature of each column 20. The first reference temperature is a temperature set in advance as a reference for interruption of the operation of the direct-current circuit breaker 1, and is a temperature lower than the allowable temperature. When the overall temperature of the plurality of columns 20 exceeds the first reference temperature, the monitor 12 determines that an anomaly that the overall temperature of the plurality of columns 20 rises has occurred. That is, the monitor 12 determines that there is an anomaly in the entirety of the plurality of columns 20. The monitor 12 outputs the determination result to the lock processor 13.

[0045] When the determination result indicating that the anomaly has occurred in the entirety of the plurality of columns 20 is input from the monitor 12, the lock processor 13 outputs a command for locking the operations of the circuit breaker 3 and the high-speed switch 6 to the operation processor 11. The operation processor 11 stops the control of the circuit breaker 3 and the high-speed switch 6 in accordance with the command from the lock processor 13. The direct-current circuit breaker 1 locks the operation for interruption by maintaining the circuit breaker 3 in the closed state and maintaining the high-speed switch 6 in the open state until the lock by the lock processor 13 is unlocked. The lock processor 13 instructs the communicator 14 to notify that the direct-current circuit breaker 1 has locked the operation for interruption. The communicator 14 transmits, to the control panel, a signal indicating that the direct-current circuit breaker 1 has locked the operation for interruption. While the direct-current circuit breaker 1 locks the operation for interruption, the power system is protected by a protection means other than the direct-current circuit breaker 1.

[0046] In the second embodiment, the direct-current circuit breaker 1 does not separate the column 20 and waits until the temperature of the plurality of columns 20 as a whole decreases. The monitor 12 continues to acquire the detection result of the temperature of each of the plurality of columns 20. The monitor 12 determines whether the temperature of each of the plurality of columns 20 has decreased to a second reference temperature. The second reference temperature is a temperature set in advance as a reference for restart of the operation by the direct-current circuit breaker 1. The second reference temperature is the same as the reference temperature in the first embodiment. The lock processor 13 unlocks the operations of the circuit breaker 3 and the high-speed switch 6 in a case where the temperature of each column 20 has decreased to the second reference temperature.

[0047] FIG. 10 is a flowchart illustrating an operation procedure of the direct-current circuit breaker according to the second embodiment. In step S11, the detector 10 measures the temperature of each column 20 constituting the lightning arrester 7. In step S12, the monitor 12 determines whether the overall temperature of the plurality of columns 20 has exceeded the first reference temperature. If the overall temperature of the plurality of columns 20 does not exceed the first reference temperature (step S12, No), the direct-current circuit breaker 1 returns the procedure to step S11.

[0048] If the overall temperature of the plurality of columns 20 has exceeded the first reference temperature (step S12, Yes), in step S13, the lock processor 13 locks the operations of the circuit breaker 3 and the high-speed switch 6 controlled by the operation processor 11. That is, the lock processor 13 locks the operation for interruption by the direct-current circuit breaker 1.

[0049] In step S14, the monitor 12 determines whether the temperature of each of the plurality of columns 20 is equal to or lower than the second reference temperature. If the temperature of each of the plurality of columns 20 is not equal to or lower than the second reference temperature (step S14, No), the direct-current circuit breaker 1 returns the procedure to step S14. If the temperature of each of the plurality of columns 20 is equal to or lower than the second reference temperature (step S14, Yes), in step S15, the lock processor 13 unlocks the operation for interruption by the direct-current circuit breaker 1. As a result, the direct-current circuit breaker 1 terminates the operation in accordance with the procedure illustrated in FIG. 10.

[0050] The direct-current circuit breaker 1 according to the second embodiment may also perform an operation similar to that in the first embodiment in a case where there is an anomaly in one or some of the plurality of columns 20. In the direct-current circuit breaker 1 according to the second embodiment, the separator 15 may be omitted in a case where an operation similar to that in the first embodiment is not performed. The direct-current circuit breaker 1 according to the second embodiment may be either a mechanical direct-current circuit breaker or a hybrid direct-current circuit breaker.

[0051] According to the second embodiment, the direct-current circuit breaker 1 determines that there is an anomaly in the entirety of the plurality of columns 20 in a case where the overall temperature of the plurality of columns 20 has risen to the first reference temperature. When the direct-current circuit breaker 1 continually performs the interruption operation and thereby the overall temperature of the plurality of columns 20 rises above the first reference temperature, the direct-current circuit breaker 1 can lock the operation for interruption. As a result, the direct-current circuit breaker 1 can obviate a failure of the lightning arrester 7 due to the rising of the overall temperature of the plurality of columns 20. Furthermore, in the direct-current circuit breaker 1, there is no need to increase the number of columns 20 with re-

spect to the energy assumed to be processed, and therefore it is possible to suppress an increase in size of the lightning arrester 7.

[0052] Next, a hardware configuration of the control circuit 8 included in the direct-current circuit breaker 1 according to the first and second embodiments will be described. A function of the control circuit 8 is realized using a processing circuitry. The processing circuitry is a processor that executes a program stored in a memory. The processing circuitry may be dedicated hardware mounted on the direct-current circuit breaker 1.

[0053] FIG. 11 is a first diagram illustrating an example of a hardware configuration of the control circuit included in the direct-current circuit breaker according to the first or second embodiment. FIG. 11 illustrates a hardware configuration in a case where the function of the control circuit 8 is realized by using hardware that executes a program. A processor 31, a memory 32, and an interface 33 are connected to each other via a bus.

[0054] The processor 31 is a central processing unit (CPU), a processing device, an arithmetic device, a microprocessor, a microcomputer, or a digital signal processor (DSP). Functions of the operation processor 11, the monitor 12, and the lock processor 13 are realized by the processor 31, and software, firmware, or a combination of software and firmware. The software or the firmware is written as a program and stored in the memory 32 as a built-in memory. The memory 32 is a nonvolatile or volatile semiconductor memory, and is a random access memory (RAM), a read only memory (ROM), a flash memory, an erasable programmable read only memory (EPROM), or an electrically erasable programmable read only memory (EEPROM (registered trademark)).

[0055] The interface 33 is responsible for signal input and signal output. The communicator 14 is realized by using the interface 33. The interface 33 outputs a command to each of the circuit breaker 3 and the high-speed switch 6. A signal indicating a detection result of a direct current obtained by the current transformer 9 is input to the interface 33.

[0056] FIG. 12 is a second diagram illustrating an example of the hardware configuration of the control circuit included in the direct-current circuit breaker according to the first or second embodiment. FIG. 12 illustrates a hardware configuration in a case where the function of the control circuit 8 is realized by using dedicated hardware. The control circuit 8 includes a processing circuitry 34 that executes various processes and the interface 33 similar to that in FIG. 11. The processing circuitry 34 and the interface 33 are connected to each other via a bus.

[0057] The processing circuitry 34 as dedicated hardware is a single circuit, a composite circuit, a programmed processor, a parallel programmed processor, an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or a combination thereof. The function of the control circuit 8 is realized by using the processing circuitry 34.

[0058] The configurations described in the embodiments above are merely examples of the content of the present disclosure. The configurations of the respective embodiments can be combined with other known technology. The configurations of the respective embodiments may be appropriately combined. Part of the configurations of the respective embodiments can be omitted or modified without departing from the gist of the present disclosure.

Reference Signs List

[0059] 1 direct-current circuit breaker; 2 direct-current line; 3 circuit breaker; 4 capacitor; 5 reactor; 6 high-speed switch; 7 lightning arrester; 8 control circuit; 9 current transformer; 10 detector; 11 operation processor; 12 monitor; 13 lock processor; 14 communicator; 15 separator; 20, 20a column; 21 upper plate; 22 lower plate; 23 support; 24 nonlinear resistive element; 25 container; 26, 27 electrode; 31 processor; 32 memory; 33 interface; 34 processing circuitry.

Claims

1. A direct-current circuit breaker including a circuit breaker adapted to interrupt a direct current flowing through a direct-current line, the direct-current circuit breaker comprising:
 - a resonant circuit including a capacitor, a reactor, and a switch connected in series to each other;
 - a lightning arrester including a plurality of columns each including a stack of a plurality of nonlinear resistive elements, the lightning arrester being connected in parallel to the capacitor;
 - an operation processor adapted to control an opening operation and a closing operation by each of the circuit breaker and the switch;
 - a monitor adapted to monitor presence or absence of an anomaly in each of the plurality of columns; and
 - a lock processor adapted to lock operations of the circuit breaker and the switch controlled by the operation processor in a case where there is an anomaly in at least one or some columns out of the plurality of columns.
2. The direct-current circuit breaker according to claim 1, wherein the monitor is adapted to monitor the presence or absence of an anomaly in each of the plurality of columns on a basis of a result of detecting a temperature of each of the plurality of columns.
3. The direct-current circuit breaker according to claim 2, wherein the monitor is adapted to determine that an anomaly has occurred in one or some columns

having a temperature rise exceeding an allowable temperature out of the plurality of columns.

4. The direct-current circuit breaker according to claim 3, comprising a separator to separate the one or some columns in which the anomaly has occurred from columns other than the one or some columns out of the plurality of columns. 5
5. The direct-current circuit breaker according to claim 4, wherein the lock processor is adapted to unlock operations of the circuit breaker and the switch in a case where a temperature of each column other than the separated one or some columns out of the plurality of columns has decreased to a reference temperature set in advance as a reference for restart of an operation. 10 15
6. The direct-current circuit breaker according to claim 2, wherein the monitor is adapted to determine that there is an anomaly in entirety of the plurality of columns in a case where an overall temperature of the plurality of columns has risen to a first reference temperature set in advance as a reference for interruption of an operation. 20 25
7. The direct-current circuit breaker according to claim 6, wherein the lock processor is adapted to unlock operations of the circuit breaker and the switch in a case where a temperature of each of the plurality of columns has decreased to a second reference temperature set in advance as a reference for restart of an operation. 30

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FIG.1

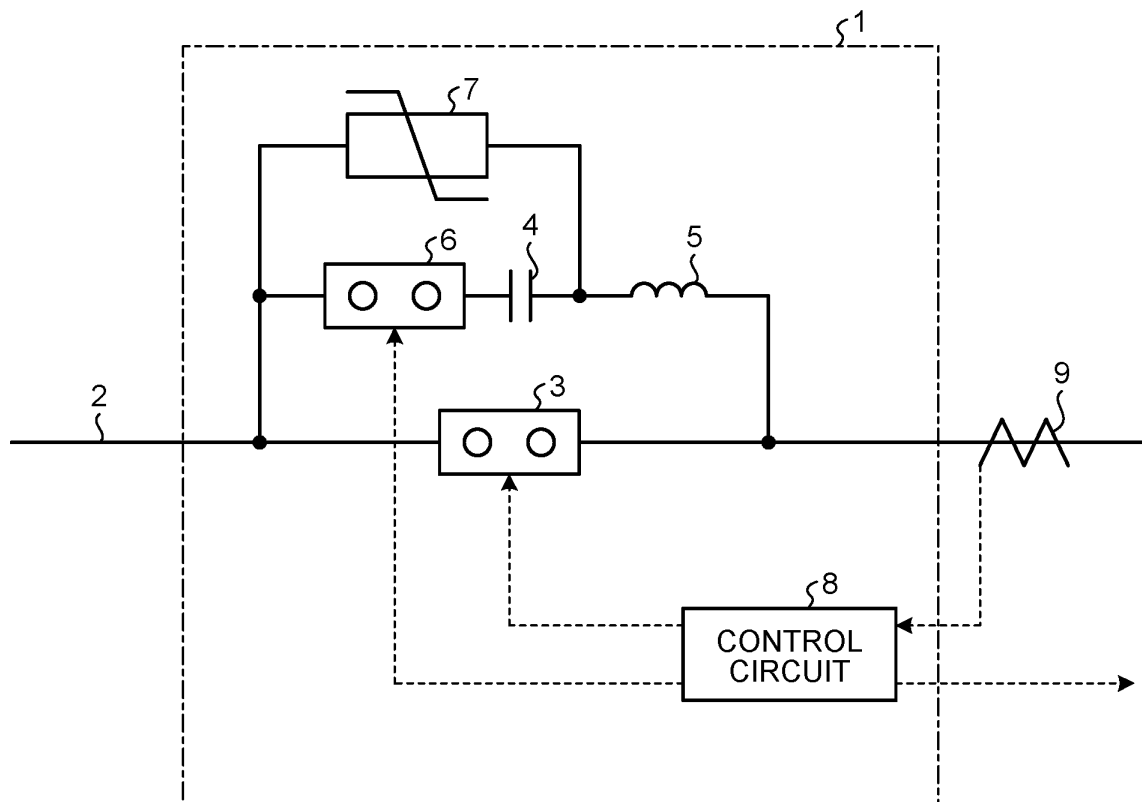


FIG.2

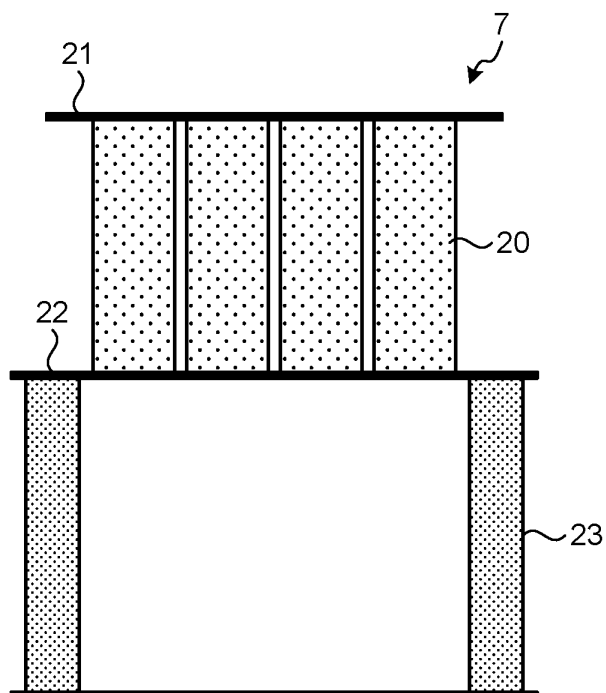


FIG.3

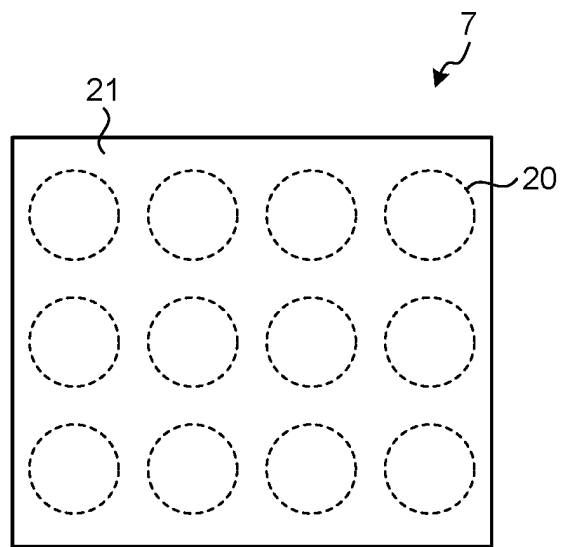


FIG.4

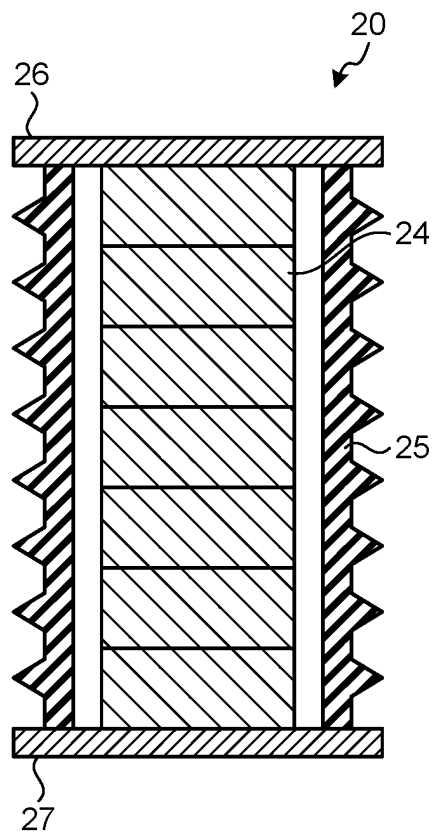


FIG.5

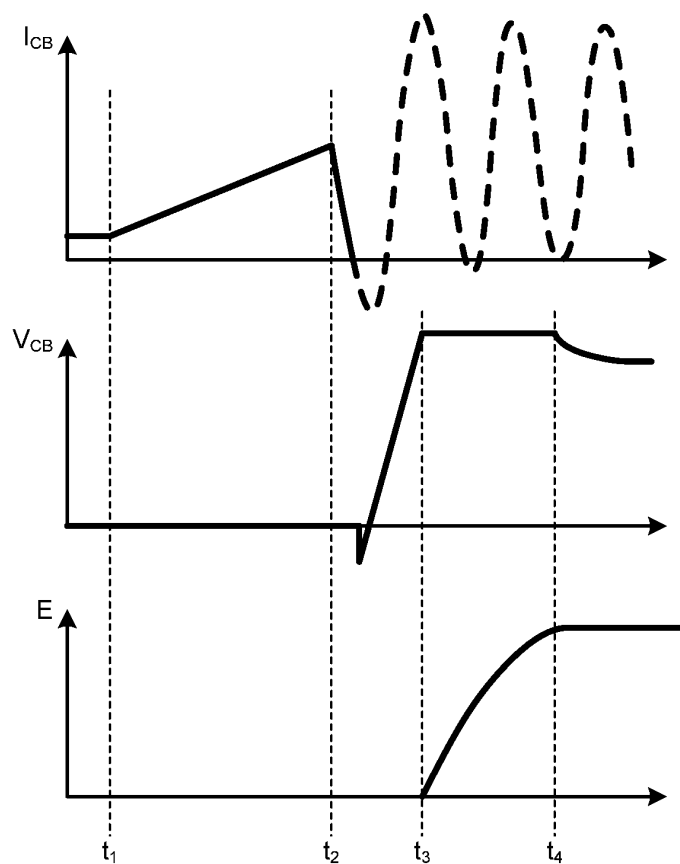


FIG.6

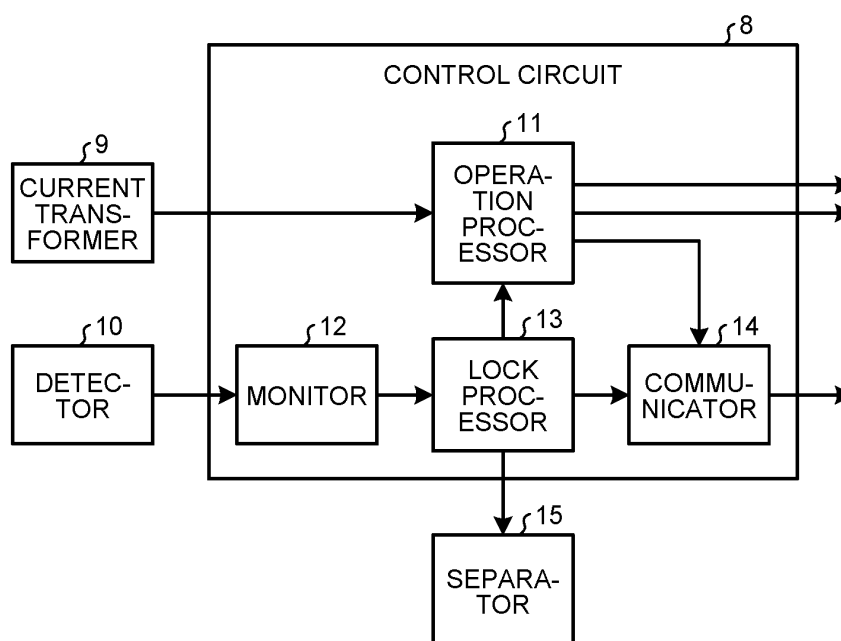


FIG.7

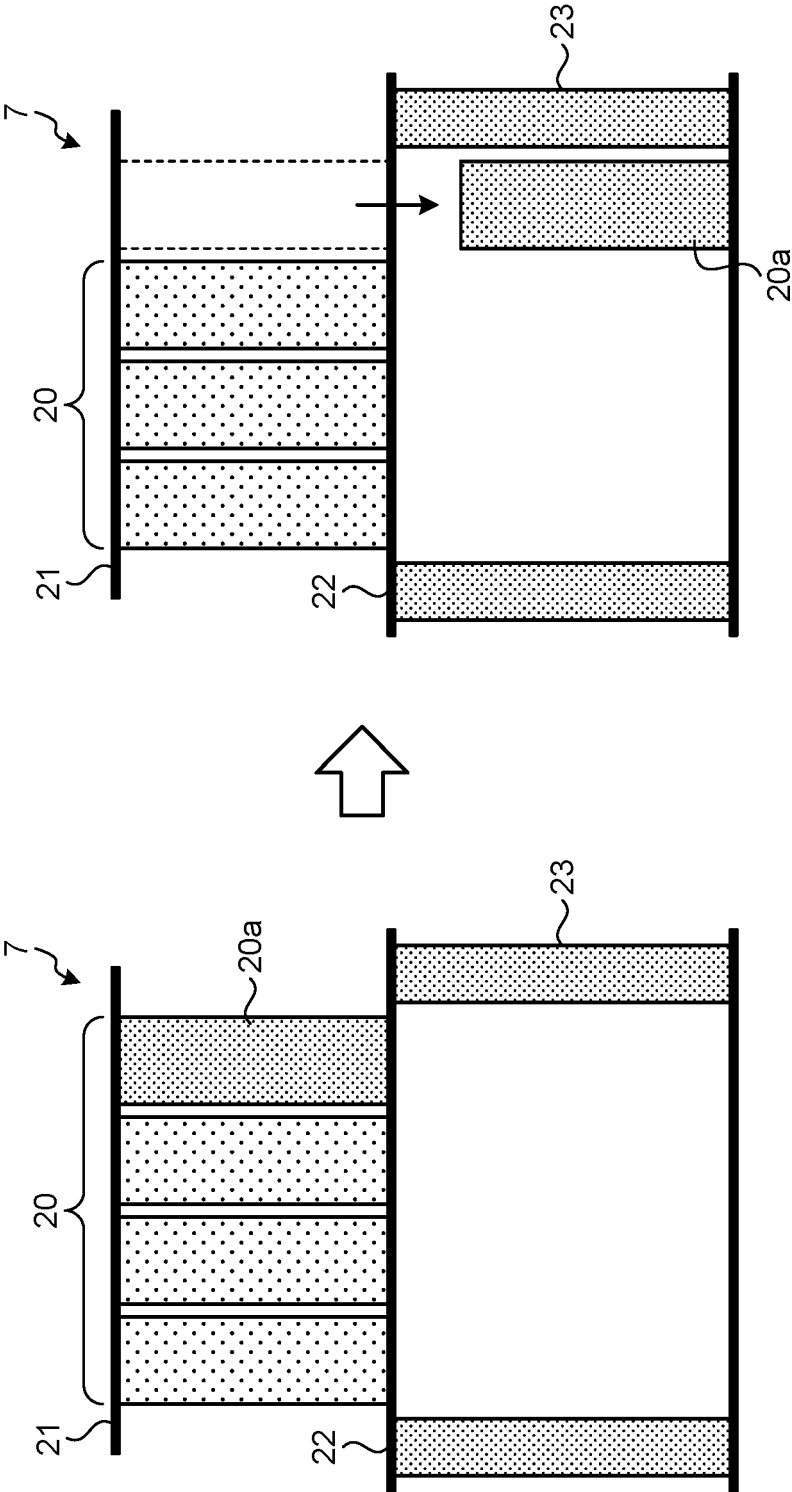


FIG.8

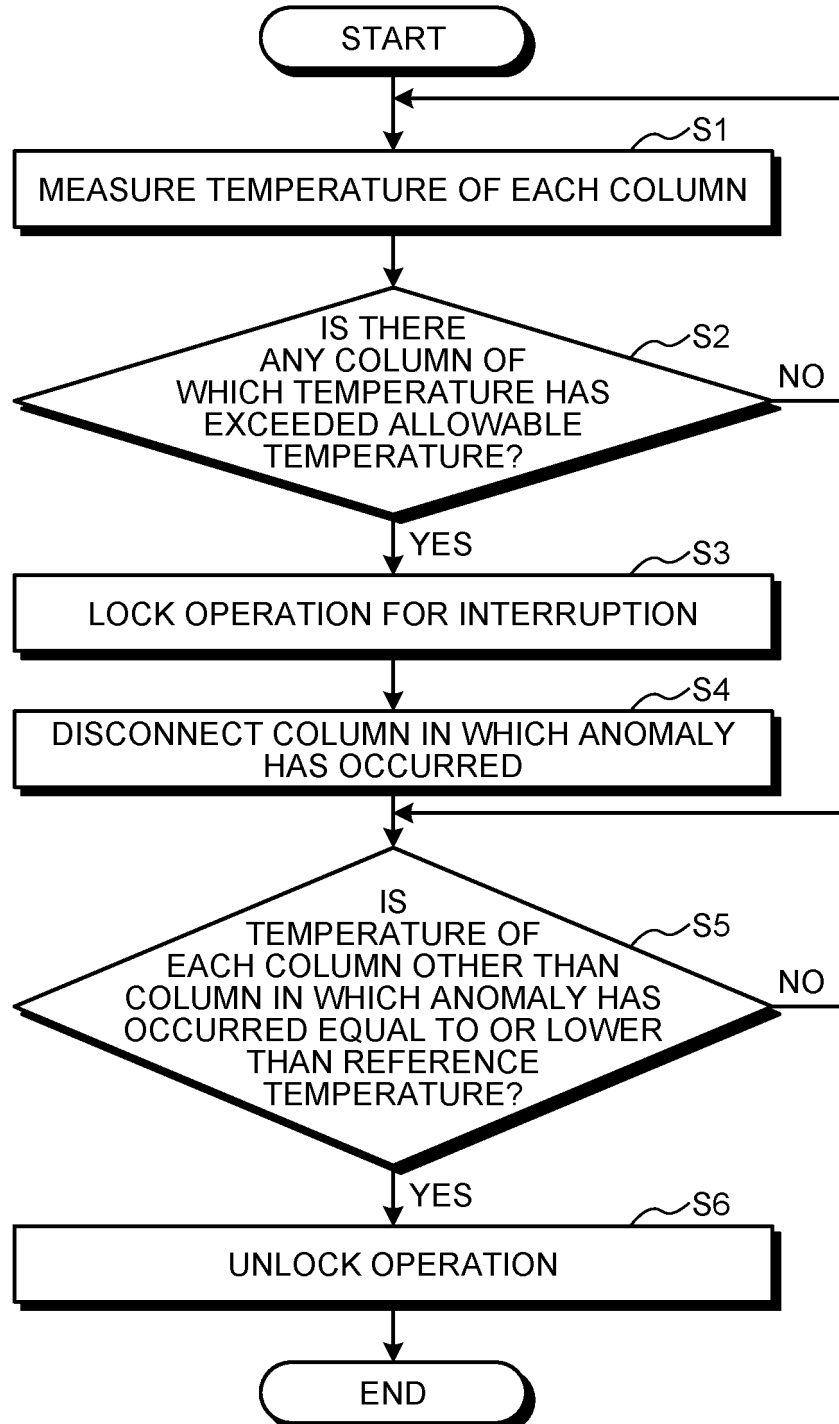


FIG.9

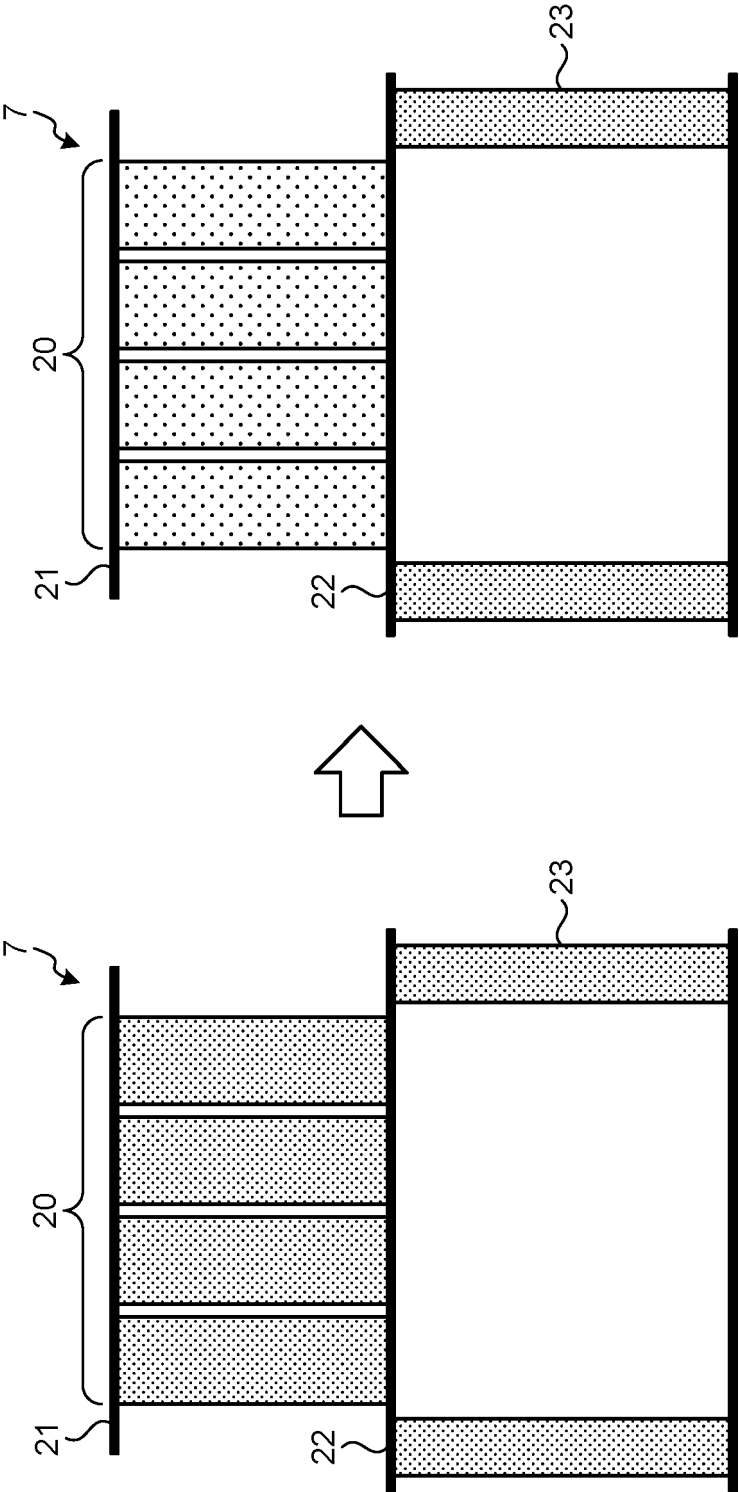


FIG.10

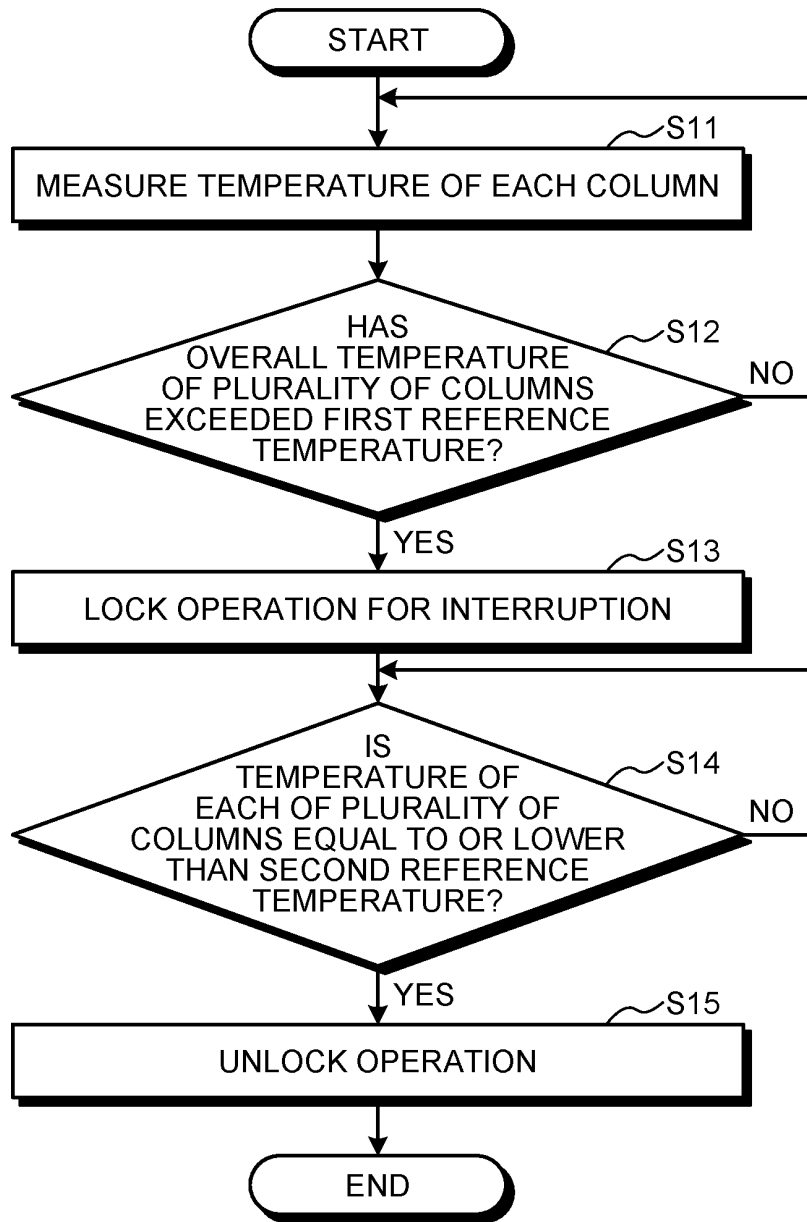


FIG.11

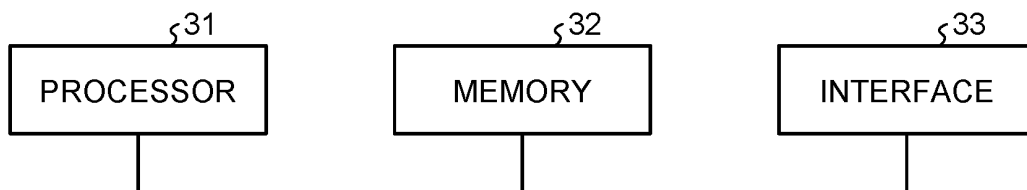
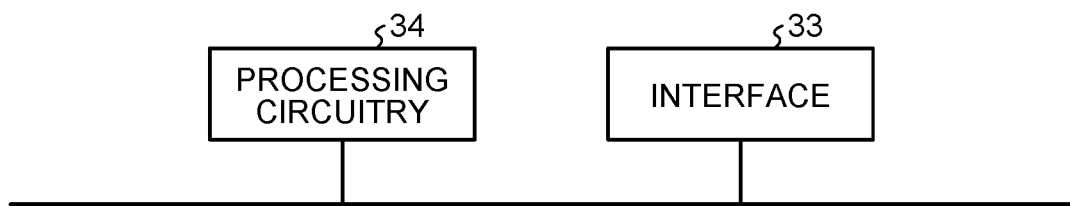


FIG.12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/001965

A. CLASSIFICATION OF SUBJECT MATTER

H01H 33/59 (2006.01) i

FI: H01H33/59 B

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, H01C7/10

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2020

Registered utility model specifications of Japan 1996-2020

Published registered utility model applications of Japan 1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 2019/012609 A1 (MITSUBISHI ELECTRIC CORP.) 17.01.2019 (2019-01-17) paragraphs [0013]-[0045], fig. 1, 4	1-3, 6-7 4-5
Y A	西脇進, 佐藤敏和, 小島宗次, 柳父悟, 酸化亜鉛型避雷器の並列接続による重責務化, 電気学会論文誌. B, 20 May 1982, vol. 102, no. 5, pp. 320-326, in particular, page 322, left column, line 12 to page 323, right column, line 3, (NISHIWAKI, Susumu, SATOH, Toshikazu, KOJIMA, Soji, YANABU, Satoru, "Realization of Heavy-duty Zinc-oxide Type Lightning Arrestors by Parallel Connection", The transactions of the Institute of Electrical Engineers of Japan. B)	1-3, 6-7 4-5



Further documents are listed in the continuation of Box C.



See patent family annex.

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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

19 March 2020 (19.03.2020)

Date of mailing of the international search report

07 April 2020 (07.04.2020)

Name and mailing address of the ISA/

Japan Patent Office

3-4-3, Kasumigaseki, Chiyoda-ku,

Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/001965

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 057344/1980 (Laid-open No. 158642/1981) (TOKYO SHIBAURA ELECTRIC CO., LTD.) 26.11.1981 (1981-11-26) page 6, line 9 to page 6, line 19, page 10, line 20 to page 11, line 1	1-3, 6-7 4-6
Y A	山崎隆, 小林隆幸, 沢武司, 水越明男, 白川吾, 交直変換所用避雷器監視装置, 電気学会論文誌. B, 20 May 1993, vol. 113, no. 4, pp. 376-382, in particular, page 377, right column, line 12 to page 379, left column, line 2, (YAMAZAKI, Tutomu, KOBAYASHI, Takayuki, SAWA, Takeshi, MIZUKOSHI, Akio, SHIRAKAWA, Shingo, "Surge Arresters Monitoring Systems in AC-DC Converter Stations", The transactions of the Institute of Electrical Engineers of Japan. B)	6-7 4-5

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2020/001965

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2019/012609 A1	17 Jan. 2019	JP 6328356 B1	
JP 56-158642 U1	26 Nov. 1981	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 59163722 A [0004]