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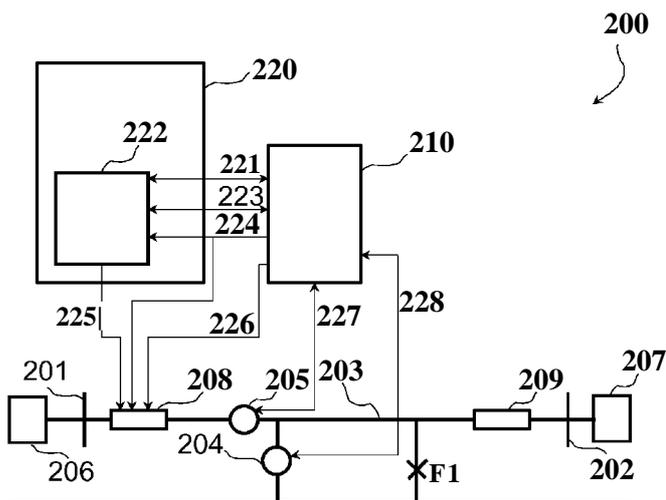
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(54) **Title:** METHOD AND DEVICE FOR DETECTION OF A FAULT IN A PROTECTED UNIT



(57) **Abstract:** A method for use in fault detection in a protected unit (203) included in a power system (200) is disclosed. The method may facilitate detection of any fault (FI) in the protected unit (203) after the protected unit (203) has been connected to the at least a portion of the rest of the power system (200). A current in the at least one current path in the protected unit (203) is sensed during a plurality of different time periods, thereby obtaining a plurality of sensed currents. The current in the at least one current path may be sensed at one end of the protected unit (203). Compliance of at least one of the sensed currents with a respective first current criteria is determined based on a first current threshold value. On a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, a signal may be generated indicating that there is a fault in the protected unit (203). On a condition that there is determined that none of the sensed currents comply with the respective first current criteria, a signal may be generated indicating that there is not a fault in the protected unit (203).

Fig. 2

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METHOD AND DEVICE FOR DETECTION OF A FAULT IN A PROTECTED
UNIT

TECHNICAL FIELD

The present invention generally relates to power systems, e.g. power transmission systems. Specifically, the present invention relates to fault detection
5 in a protected unit included in a power system, which protected unit for example may comprise a power transmission line, such as a direct current (DC) power transmission line, which may be a DC overhead line (OHL).

10 BACKGROUND

In overhead transmission lines or overhead lines (OHL) auto-reclosing protection may be utilized. A fault protection or detection unit may be employed for monitoring one or several transmission lines of a power transmission network. In the event of a fault on a transmission line, the fault
15 protection unit trips circuit breakers located at each end of the transmission line, for the purpose of disconnecting the transmission line having a fault from the rest of the power transmission network. Thereby, the risk of propagation of the fault in the power transmission network may be mitigated. Subsequently, depending on the type of fault, the circuit breakers may be
20 closed in order to restore power transmission via the transmission line that was previously disconnected from the rest of the power transmission network. This may be referred to as auto-reclosing.

In OHLs most of the faults are typically temporary or transient faults, e.g., due to lightning strokes, and an auto-reclosing protection scheme may
25 therefore be applied. On the other hand, in transmission lines based solely on cables, virtually all faults are permanent faults, and auto-reclosing is therefore not applied. Permanent faults may occur also in OHLs. In case of a permanent fault, the fault typically has to be cleared or removed by maintenance personnel.

30 Considering as an example a multi-terminal voltage source converter (VSC) based High Voltage Direct Current (HVDC) power system, faults on a DC cable or DC OHL are typically isolated from the rest of the power system or another part of the power system by temporarily shutting down the DC line, or temporarily taking the DC line out of operation, using DC circuit breakers.

For an OHL, the DC line is put back into operation after some time has passed to allow for the fault to be cleared, i.e. to allow for the fault arc current to be extinguished, in case it is a temporary fault. However, if the fault is a permanent fault, the DC line will be shut down again after reclosing it. In that case, the DC line will be shut down for a relatively long period to allow for maintenance personnel to locate and clear the fault. Events leading to DC line faults could happen both during normal operation when the DC line is energized, or when the DC line is not energized. In case the DC line is not energized when the fault occurs, the fault may only manifest itself when the DC line is attempted to be brought back into service or operation.

For faults in DC OHLs, DC circuit breakers are typically designed to auto-reclose after some time period, with the length of time period being based on the time it takes for the fault arc current to be extinguished. In case of temporary faults, the DC circuit breakers will first be tripped, and the DC line will then be restored back to normal operation following successful auto reclosing. In case of permanent faults however, the DC circuit breakers need to be tripped again after auto reclosing since there may still be a fault present in the DC line. It would therefore be desirable for a DC line protection system or mechanism to be able to detect if the fault is still present after auto reclosing has been carried out. It would also be desirable that such detection could be carried out relatively quickly, with a speed comparable to a primary protection system, due to the high rate of rise in currents occurring in e.g. VSC based HVDC power transmission systems, or grids. Similarly, it would also be desirable to be able to detect if a fault in a DC line is present after having switched DC circuit breakers in order to energize an open DC line. In energizing an open DC line, a protection mechanism should be in place to ensure that a fault is detected if there is a fault present in the DC line.

SUMMARY

In view of the above discussion, a concern of the present invention is to facilitate or even enable detection of faults, e.g. permanent faults, occurring or being present in a protected unit e.g. constituted by or including a DC line, subsequent to having carried out an auto reclosing operation or a switching operation for putting the protected unit, e.g. the DC line, back into operation.

A further concern of the present invention is to provide a scheme for detecting faults, e.g. permanent faults, occurring or being present in a

protected unit e.g. constituted by or including a DC line, subsequent to having carried out an auto reclosing operation or a switching operation for putting the protected unit, e.g. the DC line, back into operation, by which scheme the speed of the detection of faults is relatively high and/or comparable to or even higher than a speed of a primary protection system for detecting faults in such a protected unit.

To address at least one of these concerns and other concerns, a method, a fault detection device, a power system and a computer program product in accordance with the independent claims are provided. Preferred embodiments are defined by the dependent claims.

It is to be understood that for the purpose of illustrating principles of embodiments of the present invention, embodiments of the present invention are described in the following generally with reference to a portion of a power system including a protected unit, which protected unit hence may be part of a power system. The protected unit may for example comprise a DC transmission line, such as a High Voltage Direct Current (HVDC) transmission line, or several DC or HVDC transmission lines, e.g. arranged in a DC grid. The power system may for example comprise a HVDC power transmission system.

According to a first aspect of the present invention, there is provided a method for use in fault detection in a protected unit included in a power system, which protected unit is adapted to convey power via at least one current path therein. The protected unit may for example comprise a power transmission line, such as a DC power transmission line. The power transmission line may for example comprise an overhead line. The protected unit can be selectively disconnected, or isolated, from at least a portion of the rest of the power system and the protected unit can be selectively connected to at least a portion of the rest of the power system, e.g. after the protected unit has been disconnected or isolated from at least a portion of the rest of the power system. The method may allow or even enable facilitating detection of any fault in the protected unit, e.g. a permanent fault in the protected unit, after the protected unit has been connected to at least a portion of the rest of the power system, e.g. after the protected unit has been disconnected or isolated from the at least a portion of the rest of the power system. The method comprises sensing a current in at least one current path in the protected unit, e.g. at one end of the protected unit, during a plurality of different time periods, thereby obtaining a plurality of sensed currents.

Compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value is determined. On a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit is generated. On a condition that there is determined that none of the sensed currents comply with the respective first current criteria, a signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit is generated.

The generated signal or signals, and possibly any other generated signals as will be described in the following, can for example be utilized in determining whether to disconnect or isolate the protected unit from at least a portion of the rest of the power system, e.g. by tripping or opening a circuit breaker or circuit breakers. This will be further described in the following.

Sensing a current in the at least one current path in the protected unit, e.g. at one end of the protected unit, during a plurality of different time periods, thereby obtaining a plurality of sensed currents, and determining compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value, may facilitate or enable detection of whether a fault, e.g. a permanent fault, in the at least one current path or protected unit, e.g. at one end of the protected unit, is present or exists at a certain point in time. The point in time can be immediately after the protected unit has been reconnected to at least a portion of the rest of the power system, or relatively close in time to after the protected unit has been reconnected to at least a portion of the rest of the power system, e.g. immediately following auto reclosing of the circuit breakers or relatively close in time to after auto reclosing of the circuit breakers, or following energization of the at least one current path in the protected unit.

By means of sensing a plurality of currents during a plurality of different time periods such detection may be carried out relatively quickly, e.g. with a speed comparable to or even higher than a speed of a primary protection system for detecting faults in such a protected unit.

Embodiments of the present invention may allow utilizing circuit breaker auto reclosing on protected units such as DC OHLs in power systems. By utilizing circuit breaker auto reclosing on DC OHLs it may not be necessary to shut down the DC line or DC link whenever a fault occurs in the power system, e.g. a DC grid. Auto reclosing circuit breakers on a DC line may reduce or even minimize the outage time of the DC line, which may

improve the overall operation of the entire power system at least with respect to reducing or minimizing time when not in operation. As will become further evident from the following description, the generated signal or signals may be utilized in determining whether to disconnect the protected unit from at least a
5 portion of the rest of the power system.

In the foregoing and in the following description, including the description referring to the drawings, sensing of current and possibly voltage in at least one current path in the protected unit for use in fault detection in the protected unit is mainly described with reference to an example where
10 current and possibly voltage are sensed at one end of the protected unit. It is to be understood that this is merely for illustrating principles of the embodiments of the present invention and should not be considered as limiting. Rather, it is to be understood that such sensing of current and possibly voltage can be implemented at more than one end of the protected
15 unit, e.g. at both ends of the protected unit in case it includes or is constituted by a transmission line, so as to facilitate or even enable fault detection in the protected unit at more than one end of the protected unit. This will be further described in the following.

In the context of the present application, by a plurality of different time
20 periods it is meant at least two different time periods.

It is to be understood that in the context of the present application the term "time period", particularly when referring to sensing a current and/or a voltage, encompasses both the case of an instant or moment in time and the case of a time period having a certain duration, e.g. during which time period a
25 current or voltage is sensed.

The protected unit may for example comprise a DC transmission line, such as a HVDC transmission line, or several DC or HVDC transmission lines e.g. arranged in a grid, which may be referred to as a DC grid. The power system may comprise a HVDC power transmission system. HVDC
30 transmission lines may be arranged in configurations such as monopole, symmetric monopole, or bipolar configurations. For example, a bipolar HVDC transmission line comprises a positive pole line, a negative pole line, and a metallic return line connected to ground. Faults that may occur on a bipolar HVDC transmission line include positive pole to negative pole short circuits,
35 positive pole to ground short circuits, and negative pole to ground short circuits. Embodiments of the present invention may for example be implemented in the positive pole line and/or the negative pole line of a bipolar

HVDC transmission line, or in other transmission line configurations that can be envisaged by the person skilled in the art. In other words, the protected unit may be included in the positive pole line and/or the negative pole line of a bipolar HVDC transmission line, or in another transmission line configuration.

5 An absolute value of at least one of the sensed currents, e.g. sensed in the at least one current path at one end of the protected unit, may be determined. Compliance of the absolute value with a second current criteria based on a second current threshold value may be determined. On a condition that there is determined that the absolute value complies with the
10 second current criteria, a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit may be generated. On a condition that there is determined that the absolute value complies with the second current criteria, a signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit may be generated.

15 Such signalling based on determination of an absolute value of at least one of the sensed currents, e.g. sensed in the at least one current path at one end of the protected unit, may according to one embodiment of the present invention provide a back-up protection functionality to the signalling based on sensing current in the at least one current path in the protected unit, e.g. at
20 one end of the protected unit, during a plurality of different time periods, whereby a plurality of sensed currents are obtained, in case the latter signalling fails to detect a fault in the protected unit even though there is a fault in the protected unit. The second current criteria may for example be whether the determined absolute value exceeds the second current threshold
25 value, where in case the determined absolute value exceeds the second current threshold value, a signal indicating that there is a fault in the protected unit is generated.

 A voltage of at least one current path in the protected unit, e.g. at one end of the protected unit, may be sensed. For example, a voltage between
30 the at least one current path in the protected unit at one end of the protected unit and ground may be sensed. Compliance of the sensed voltage with a voltage criteria based on a voltage threshold value may be determined. On a condition that there is determined that the sensed voltage complies with the voltage criteria, a signal indicating that there is a fault, e.g. a permanent fault,
35 in the protected unit may be generated. On a condition that there is determined that the sensed voltage complies with the voltage criteria, a signal

indicating that there is not a fault, e.g. a permanent fault, in the protected unit may be generated.

When a protected unit such as a DC line is restored back to normal operation following successful auto reclosing, and there is no fault in the DC
5 line, the line side voltage will initially 'jump' to the rated DC line voltage, and then oscillate about the rated DC line voltage, due to the nature of an RLC circuit, as known to a person skilled in the art. Eventually the line side voltage will be at or substantially at the rated DC line voltage after steady state conditions have been reached. The sensing of the voltage, determination of
10 the sensed voltage with the voltage criteria and generation of a signal as described above may be referred to as an overvoltage blocking functionality. Implementing such functionality may facilitate or even enable using relatively sensitive settings for the signalling based on sensing current in the at least one current path in the protected unit during a plurality of different time
15 periods, whereby a plurality of sensed currents are obtained, e.g. facilitating or even enabling use of a relatively sensitive first current criteria based on a first current threshold value.

On a condition that at least one of the generated signal or signals indicates that there is a fault in the protected unit, a first derived signal
20 indicating that there is a fault, e.g. a permanent fault, in the protected unit may be generated. On a condition that none of the generated signal or signals indicate that there is a fault, e.g. a permanent fault, in the protected unit, a first derived signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit may be generated.

25 A voltage of the at least one current path in the protected unit, e.g. at one end of the protected unit, may be sensed. For example, a voltage between the at least one current path in the protected unit at one end of the protected unit and ground may be sensed. Compliance of the sensed voltage with a voltage criteria based on a voltage threshold value may be determined.
30 On a condition that there is determined that the sensed voltage complies with the voltage criteria, a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit may be generated. On a condition that there is determined that the sensed voltage complies with the voltage criteria, a signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit
35 may be generated. On a condition that both of the generated signal and the first derived signal indicate that there is a fault, e.g. a permanent fault, in the protected unit, a second derived signal indicating that there is a fault, e.g. a

permanent fault, in the protected unit may be generated. On a condition that both of the generated signal and the first derived signal indicate that there is not a fault, e.g. a permanent fault, in the protected unit, a second derived signal indicating that there is not a fault, e.g. a permanent fault, in the
5 protected unit may be generated.

The generation of first and second derived signals as described above will be further described below with reference to Figs. 5-12, where for example the first derived signal can be represented by the signal output from the L1 logical unit and/or the L2 logical unit, and the second derived signal
10 can be represented by the signal output from the L3 logical unit (Figs. 5, 6, 8 and 9), or the first derived signal can be represented by the signal output from the L1 logical unit (Figs. 7 and 10-12).

For example, a current in the at least one current path in the protected unit may be sensed during at least three different respective time instants ($t_1 - t_0$), ($t_2 - t_0$), ($t_3 - t_0$), where t_0 is a time at which the protected unit is connected to
15 the at least a portion of the rest of the power system after having been disconnected or isolated from the at least a portion of the rest of the power system, and $t_3 > t_2 > t_1 > t_0$. Thereby, at least three sensed currents $I(t_1 - t_0)$, $I(t_2 - t_0)$, and $I(t_3 - t_0)$ may be obtained.

The time instant ($t_1 - t_0$) may for example be determined by a time for a
20 fault current in the at least one current path in the protected unit to reach a maximum discharging or inrush current subsequent to the protected unit having been connected to the at least a portion of the rest of the power system after having been disconnected or isolated from the at least a portion
25 of the rest of the power system, on a condition that the fault occurs close to or at a terminal, e.g. a voltage source converter, to which the protected unit is connected.

In the context of the present application, by the fault occurring close to or at a terminal, e.g. a voltage source converter, to which the protected unit is
30 connected, it is meant that the fault occurs or is present at a maximum distance from the terminal of about a few percent or less of the length of the at least one current path, e.g. including a power transmission line. For example, in case the length of the power transmission line is between 500 km to 1000 km, the fault occurring close to a terminal, e.g. a voltage source
35 converter, to which the protected unit is connected may mean that the fault occurring within a few kilometers, e.g. two to five kilometers or more, from the terminal.

The time instant $(t_2 - t_0)$ may for example be determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value on a condition that the fault occurs at or close to a middle point of the at least one current path in the protected unit.

5 In the context of the present application, by the fault occurring at or close to a middle point of the at least one current path, it is meant that the fault occurs or is present at a maximum distance from the middle point of the at least one current path of about a few percent or less of the length of the at least one current path.

10 The time instant $(t_3 - t_0)$ may for example be determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value on a condition that the fault occurs at or close to an end point of the at least one current path in the protected unit.

15 In the context of the present application, by the fault occurring at or close to an end point of the at least one current path, it is meant that the fault occurs or is present at a maximum distance from the end point of the at least one current path of about a few percent or less of the length of the at least one current path.

20 By sensing a current in the at least one current path in the protected unit during different respective time instants, e.g. during at least three different respective time instants (M_0) , $(t_2 - t_0)$, (M_0) as described in the foregoing, detection of fault in the protected unit with speed faster than so called over-current protection schemes may be facilitated, and/or detection of any fault occurring over the whole or substantially the whole of the length of
25 the at least one current path, with relatively high speed and/or speed comparable to a speed of a primary protection system for detecting faults in such a protected unit, may be facilitated.

30 According to another example, a current in the at least one current path in the protected unit may be sensed continuously during a time window (M_0) , where t_0 is a time at which the protected unit is connected to the at least a portion of the rest of the power system after having been disconnected or isolated from the at least a portion of the rest of the power system, and t_1 is a time such that $t_1 > t_0$. The time window $(t_1 - t_0)$ may for example be determined by a time for a fault current in the at least one current path in the
35 protected unit to reach the first current threshold value on a condition that the fault occurs at or close to an end point of the at least one current path in the protected unit. Determining compliance of at least one of the sensed currents

with a respective first current criteria based on a first current threshold value may for example comprise determining at least one quotient of a difference between currents $I(t_1)$ and $I(t_0)$, where t denotes time, and a difference between t and t_0 , and comparing the determined at least one quotient during
5 the time window (t_1-t_0) with a current slope threshold value, wherein the current slope threshold value constitutes the first current threshold value.

Determining compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value may for example comprise determining a quotient of a difference between currents
10 $I(t_1)$ and $I(t_0)$ and a difference between t_1 and t_0 , and comparing the quotient with a current slope threshold value, wherein the current slope threshold value constitutes the first current threshold value.

For example, on a condition that the quotient exceeds the current slope threshold value, compliance of at least one of the sensed currents with a
15 respective first current criteria based on a first current threshold value may be determined, and a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit may then be generated.

According to other examples, a current in the at least one current path in the protected unit may be sensed during at least three or four or more
20 different respective time instants.

According to a second aspect of the present invention, there is provided a fault detection device for detection of a fault in a protected unit included in a power system, which protected unit is adapted to convey power via at least one current path therein. The protected unit can be selectively
25 disconnected or isolated from at least a portion of the rest of the power system and the protected unit can be selectively connected to the at least a portion of the rest of the power system, e.g. after the protected unit has been isolated from the at least a portion of the rest of the power system. The fault detection device is adapted to facilitate detection of any fault, e.g. permanent
30 fault, in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system, e.g. after the protected unit has been disconnected or isolated from the at least a portion of the rest of the power system. The fault detection device comprises a current sensor unit and a processing unit. The current sensor unit is adapted to sense a current in the
35 at least one current path in the protected unit, e.g. at one end of the protected unit, during a plurality of different time periods, thereby obtaining a plurality of sensed currents. The processing unit is coupled to the current sensor unit,

e.g. so as to at least enable communication of signals, messages, instructions and/or data between the processing unit and the current sensor unit. The processing unit is adapted to determine compliance of at least one of the sensed currents with a respective first current criteria based on a first current
5 threshold value. The processing unit is adapted to, on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit. The processing unit is adapted to, on a condition that there is determined that none of the sensed
10 currents comply with the respective first current criteria, generate a signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit.

The processing unit may be adapted to: determine the absolute value of at least one of the sensed currents, determine compliance of the absolute value with a second current criteria based on a second current threshold
15 value, on a condition that there is determined that absolute value complies with the second current criteria, generate a signal indicating that there is a fault, e.g. a permanent fault, in the protected unit, and, on a condition that there is determined that the absolute value complies with the second current criteria, generate a signal indicating that there is not a fault, e.g. a permanent
20 fault, in the protected unit.

The fault detection device may comprise a voltage sensor unit adapted to sense a voltage of the at least one current path in the protected unit, e.g. at one end of the protected unit. For example, the fault detection device may be adapted to sense a voltage between the at least one current path in the
25 protected unit and ground at one end of the protected unit.

The processing unit may be adapted to: determine compliance of the sensed voltage with a voltage criteria based on a voltage threshold value, on a condition that there is determined that the sensed voltage complies with the voltage criteria, generate a signal indicating that there is a fault, e.g. a
30 permanent fault, in the protected unit, and, on a condition that there is determined that sensed voltage complies with the voltage criteria, generate a signal indicating that there is not a fault, e.g. a permanent fault, in the protected unit.

According to a third aspect of the present invention, there is provided a
35 power system including a protected unit adapted to convey power via at least one current path therein, wherein the protected unit can be selectively disconnected or isolated from at least a portion of the rest of the power

system, and the protected unit can be selectively connected to the at least a portion of the rest of the power system, e.g. after the protected unit has been disconnected or isolated from the at least a portion of the rest of the power system. The power system includes a fault detection device according to the
5 second aspect of the present invention, which fault detection device is adapted to facilitate detection of any fault, e.g. permanent fault, in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system, e.g. after the protected unit has been disconnected or isolated from the at least a portion of the rest of the power
10 system.

The power system may comprise at least one DC circuit breaker adapted to selectively disconnect or isolate the protected unit from the at least a portion of the rest of the power system upon receipt of a disconnection signal, and selectively connect the protected unit to the at least a portion of
15 the rest of the power system upon receipt of a connection signal. The fault detection device is communicatively coupled to the at least one DC circuit breaker, e.g. so as to at least enable communication of signals, messages, instructions and/or data between the fault detection device and the at least one DC circuit breaker. The processing unit of the fault detection device is
20 adapted to, on a condition that at least one of the generated signals indicate that there is a fault, e.g. a permanent fault, in the protected unit, generate a disconnection signal and transmit the disconnection signal to the at least one DC circuit breaker, whereby the protected unit becomes disconnected or
isolated from the at least a portion of the rest of the power system.

25 The power system may for example comprise a High Voltage Direct Current (HVDC) power transmission system.

According to a fourth aspect of the present invention, there is provided a computer program product adapted to be executed in a processing unit of a fault detection device in a power system. The computer program product
30 comprises computer-readable means carrying computer program code. The power system includes a protected unit that can be selectively isolated from at least a portion of the rest of the power system and that can be selectively re-connected to the at least a portion of the rest of the power system after having been isolated from the at least a portion of the rest of the power
35 system. The fault detection device is adapted to facilitate detection of any fault in the protected unit after the protected unit has been re-connected to the at least a portion of the rest of the power system after having been

isolated from the at least a portion of the rest of the power system. The fault detection device comprises a current sensor unit coupled to the processing unit. The current sensor unit is adapted to sense a current in the at least one current path in the protected unit, e.g. at one end of the protected unit, at
5 least once. The computer program code is configured to, when executed in the processing unit of the fault detection device, cause the current sensor unit to sense a current in the at least one current path in the protected unit e.g. at one end of the protected unit during a plurality of different time periods, thereby obtaining a plurality of sensed currents. The computer program code
10 is configured to, when executed in the processing unit of the fault detection device, determine compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value. The computer program code is configured to, when executed in the processing unit of the fault detection device, on a condition that there is determined that
15 at least one of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is a fault in the protected unit, and, on a condition that there is determined that none of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is not a fault in the protected unit.

20 The processing unit of the fault detection device may include or be constituted by any suitable central processing unit (CPU), microcontroller, digital signal processor (DSP), Application Specific Integrated Circuit (ASIC), Field Programmable Gate Array (FPGA), etc., or any combination thereof. The processing unit may optionally be capable of executing software
25 instructions stored in a computer program product e.g. in the form of a memory. The memory may for example be any combination of read and write memory (RAM) and read-only memory (ROM). The memory may comprise persistent storage, which for example can be a magnetic memory, an optical memory, a solid state memory or a remotely mounted memory, or any
30 combination thereof.

Further objects and advantages of the present invention are described in the following by means of exemplifying embodiments.

It is noted that the present invention relates to all possible combinations of features recited in the claims. Further features of, and
35 advantages with, the present invention will become apparent when studying the appended claims and the following description. Those skilled in the art will

realize that different features of the present invention can be combined to create embodiments other than those described in the following.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Exemplifying embodiments of the invention will be described below with reference to the accompanying drawings, in which:

Fig. 1 is a circuit representation that illustrates a section of a power system according to an example;

10 Figs. 2 and 3 are circuit representations that illustrate a section of respective power systems in accordance with embodiments of the present invention;

Fig. 4 is a schematic flowchart illustrating a method according to an embodiment of the present invention;

15 Figs. 5-12 are logic diagrams illustrating methods according to embodiments of the present invention; and

Fig. 13 is a circuit representation that illustrate a section of a power system in accordance with an embodiment of the present invention.

20 In the accompanying drawings, the same reference numerals denote the same or similar elements throughout the views. All the figures are schematic, not necessarily to scale, and generally only show parts which are necessary in order to elucidate the invention, wherein other parts may be omitted or merely suggested.

25

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplifying embodiments of the present invention are shown. The present invention may, however, be
30 embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will convey the scope of the invention to those skilled in the art. Furthermore, like numbers refer to like or similar elements or components throughout. The steps of any method described
35 herein do not have to be performed in the exact order as described, unless specifically stated.

In DC grid systems, fault isolation is anticipated to be carried out utilizing DC circuit breakers without shutting down converters. Such a strategy is intended to preserve the integrity of the DC grid by allowing rerouting of DC power through other, non-faulty, DC lines. Even remote faults could

5 potentially lead to so called voltage collapse, so it is desirable that DC circuit breakers open relatively quickly. For a DC overhead line (OHL), a fault could be either a temporary fault or a permanent fault. To protect the DC grid system against temporary faults, or even to secure or maintain operation of the DC grid system when temporary faults occur, DC circuit breaker auto

10 reclosing is anticipated to be a part of the recommended operating procedure for DC grids. In the case of a permanent fault, the primary protection system should be able to detect the fault following auto reclosing, and then again disconnect the faulty DC line. Similarly, it is also expected that the primary protection system should be operational during DC line switching operations.

15 Primary protections have been designed to detect positive (negative) rate of rise of DC currents and negative (positive) rate of rise of DC voltage of the DC line subsequent to a fault occurring, which protection scheme involves the positive (negative) pole under normal DC line operating conditions. However, these current and voltage time derivative based primary protections

20 which are designed to protect the DC line under normal operating conditions may not be able to detect permanent faults sufficiently quickly and reliably following DC circuit breaker auto reclosing.

Referring now to Fig. 1, which shows a circuit representation which illustrates a section of a multi-terminal High Voltage Direct Current (HVDC)

25 grid 100, a protected unit 103 in the form of a transmission line 103, here exemplified by a DC OHL 103, interconnects buses 101 and 102. A voltage sensor 104 and a current sensor 105 are arranged on the line side, which voltage sensor 104 and a current sensor 105 are used by a primary protection system (not shown in Fig. 1) in order to trip circuit breaker CB1 in case of DC

30 OHL 103 faults. The current in one end of the transmission line 103, e.g. the end of the transmission line 103 on the left-hand side of Fig. 1, is measured by the current sensor 105 and the voltage in one end of the transmission line 103 between the transmission line 103 and ground is measured by the voltage sensor 104. At the other end of the transmission line 103, i.e. the end

35 of the transmission line 103 on the right-hand side of Fig. 1, there may be arranged a voltage sensor and current sensor (not shown in Fig. 1) similarly as voltage sensor 104 and current sensor 105, which e.g. may substantially

measure the voltage and current in the other end of the protected unit 103 to supply signal inputs to the primary protection system (not shown in Fig. 1) to trip circuit breaker CB2 in case of DC OHL 103 faults so that the complete DC OHL 103 could be disconnected by CB1 and CB2 if there is a fault in DC OHL

5 103. Following a fault F1 in the transmission line 103, it will be isolated from the rest of the HVDC grid 100 by opening of circuit breakers CB1, CB2 arranged at both ends of the transmission line 103, as illustrated in Fig. 1, which shows both of the circuit breakers CB1, CB2 in an open state. While the circuit breakers CB1, CB2 are kept opened for a certain period of time

10 before auto reclosing, the transmission line 103 is un-energized from both sides of the transmission line 103. The voltage sensor 104 and the current sensor 105 in one of the ends of the transmission line 103 are arranged on the line side, and before auto reclosing of the circuit breaker CB1, the voltage sensor 104 and the current sensor 105 will therefore exhibit negligible voltage

15 and current readings, respectively. When the circuit breakers CB1, CB2 auto reclose, converters 106, 107 will provide grid voltage in the transmission line 103. Thus, the voltage in the transmission line 103 will jump to the rated line voltage shortly after auto reclosing of the circuit breakers CB1, CB2. Once the fault F1 begins to draw current, the voltage in the transmission line 103 will

20 start to diminish and eventually be reduced to zero or substantially zero if the fault F1 is not isolated. Thus, following auto reclosing of the circuit breakers CB1, CB2, the positive (negative) pole primary protection system will initially 'see' positive (negative) rate of rise of voltage. When utilizing voltage derivative based fault detection criteria, the signs of voltage derivatives

25 following a fault occurring and auto reclosing are in general opposite and the initial voltage derivatives under permanent and temporary fault conditions may be quite close following auto reclosing. When the circuit breakers CB1, CB2 auto recloses, the current in the transmission line 103 will increase. The rate of increase of the current in the transmission line 103 may be limited by

30 the reactors and the reactance of the transmission line 103. The fault current is initially contributed to by capacitive devices included in the HVDC grid 100, and is after some time fed by the AC grid and other sources directly connected to the HVDC grid 100. Eventually, the fault current will reach a maximum value at steady state if the fault F1 is not isolated. Thus, following

35 auto reclosing of the circuit breakers CB1, CB2, the positive (negative) pole primary protection will 'see' positive (negative) rate of rise of current. When utilizing current derivative based fault detection criteria, the initial current

derivatives following a fault occurring and auto reclosing may be almost the same and the initial current derivatives under permanent and temporary fault conditions may be almost the same following auto reclosing.

Similar concerns apply when switching a circuit breaker to energize an open transmission line. In energizing a transmission line, a protection system
5 needs to be in operation in order to detect a possible fault. Energizing an open transmission line by closing a circuit breaker will result in positive (negative) rate of rise of voltage in the positive (negative) pole. The initial voltage and current derivatives when switching to a non-faulty transmission
10 line and when switching to a transmission line in which a fault is present may be almost the same.

Referring now to Fig. 2 there is shown a circuit representation which illustrates a section of a power system 200 exemplified by a multi-terminal High Voltage Direct Current (HVDC) grid 200, in accordance with an
15 embodiment of the present invention. The power system 200 includes a protected unit 203, which protected unit 203 is adapted to convey power via at least one current path (not explicitly indicated in Fig. 2) therein. According to the embodiment depicted in Fig. 2, the protected unit 203 includes a transmission line 203, here exemplified by a DC OHL 203. The protected unit
20 203, which in the following will mostly be referred to as transmission line 203, interconnects buses 201 and 202. A voltage sensor 204 and a current sensor 205 are arranged on the line side at one end of the transmission line 203, e.g. the end of the transmission line 203 on the left-hand side of Fig. 2. The current through the transmission line 203 in one end of the transmission line
25 203 is measured by the current sensor 205 and the voltage in one end of the transmission line 203 between the transmission line 203 and ground is measured by the voltage sensor 204. The transmission line 203 can be selectively disconnected or isolated from at least a portion of the rest of the power system 200, and the transmission line 203 can be selectively
30 connected to the at least a portion of the rest of the power system 200, e.g. after the transmission line 203 has been isolated from the at least a portion of the rest of the power system 200, by means of opening, or tripping, and/or closing at least one of DC circuit breakers 208, 209. For example, the circuit breakers 208, 209 can be tripped following a fault F1 on the transmission line
35 203 and then auto reclosed after a certain period of time. When the circuit breakers 208, 209 auto reclose, converters 206, 207 can provide grid voltage in the transmission line 203.

The power system 200 includes a transmission line 203 protection system 210 for protection of the transmission line 203, and possibly at least a portion of the rest of the power system 200, against faults occurring in the transmission line 203.

5 The power system 200 includes a fault detection device 220 coupled to the protection system 210. The fault detection device 220 is adapted to detect any fault F1, e.g. a permanent fault, in the transmission line 203 after the transmission line 203 has been connected to the at least a portion of the rest of the power system 200, e.g. after the transmission line 203 has been
10 disconnected or isolated from the at least a portion of the rest of the power system 200. The fault detection device 220 comprises a current sensor unit and a processing unit 222.

 According to the embodiment depicted in Fig. 2, the current sensor unit of the fault detection device 220 is embodied by means of the current sensor
15 205 coupled to the fault detection device 220 via the protection system 210. However, the current sensor unit of the fault detection device 220 may be constituted by at least one current sensor directly coupled to the fault detection device 220, which at least one current sensor is adapted to measure current in the transmission line 203.

20 The current sensor unit 205 is adapted to sense a current in the transmission line 203, or in the at least one current path in the protected unit 203, during a plurality of different time periods, thereby obtaining a plurality of sensed currents, indicated by reference numeral 227 in Fig. 2. As illustrated in Fig. 2, the processing unit 220 is coupled to the current sensor unit, e.g. so
25 as to at least enable communication of signals, messages, instructions and/or data between the processing unit 222 and the current sensor unit 205. As indicated by reference numeral 221 in Fig. 2, the sensed currents or sensed current values can be conveyed to the processing unit 222 of the fault detection device 220 via the protection system 210.

30 The fault detection device 220 may comprise a voltage sensing unit adapted to sense a voltage of the transmission line 203 or a voltage of the at least one current path in the protected unit 203, e.g. to sense a voltage between the transmission line 203 and ground or a voltage between the at least one current path in the protected unit 203 and ground.

35 According to the embodiment depicted in Fig. 2, the voltage sensor unit of the fault detection device 220 is embodied by means of the voltage sensor 204 coupled to the fault detection device 220 via the protection system 210.

However, the voltage sensor unit of the fault detection device 220 may be constituted by at least one voltage sensor directly coupled to the fault detection device 220, which at least one voltage sensor is adapted to measure voltage of the transmission line 203 or protected unit 203.

5 The voltage sensor unit 204 is coupled to the processing unit 222, e.g. so as to at least enable communication of signals, messages, instructions and/or data between the processing unit 222 and the voltage sensor unit 204. In Fig. 2, the communication of sensed voltage or sensed voltage value is indicated by reference numeral 228. As indicated by reference numeral 223 in
10 Fig. 2, sensed voltage or sensed voltage value can be conveyed to the processing unit 222 of the fault detection device 220 via the protection system 210.

The processing unit 222 is adapted to determine compliance of at least one of the sensed currents with a respective first current criteria based on a
15 first current threshold value. The processing unit 222 is adapted to, on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is a fault F1, e.g. a permanent fault, in the transmission line 203, which generated signal or a signal derived based on the generated signal
20 may be transmitted to the circuit breaker 208, as indicated by reference numeral 225 in Fig. 2, and/or to circuit breaker 209 so as to cause the circuit breaker 208 and/or circuit breaker 209 to open or to be tripped. The processing unit 222 may be adapted to, on a condition that there is determined that none of the sensed currents comply with the respective first
25 current criteria, generate a signal indicating that there is not a fault, e.g. a permanent fault, in the transmission line 203.

The protection system 210 may be adapted to transmit a signal, indicated in Fig. 2 by reference numeral 226, to circuit breaker 208 so as to cause the circuit breaker 208 to open. In addition or in alternative, the
30 protection system 210 may be adapted to transmit a signal to circuit breaker 209 so as to cause the circuit breaker 209 to open (not shown in Fig. 2).

The protection system 210 may be adapted to transmit a signal to the circuit breaker 208 so as to cause the circuit breaker 208 to auto reclose, indicated in Fig. 2 by reference numeral 224. In addition or in alternative, the
35 protection system 210 may be adapted to transmit a signal to circuit breaker 209 so as to cause the circuit breaker 209 to auto reclose (not shown in Fig. 2). The signal 224 may in alternative or in addition be transmitted to the fault

detection device 220, which in turn can convey the signal 224 to the circuit breaker 208. This will be further described in the following.

At the other end of the transmission line 203, i.e. at the end of the transmission line 203 on the right-hand side of Fig. 2, there may be arranged
5 a voltage sensor and current sensor (not shown in Fig. 2) which e.g. may substantially mirror or be similar to the arrangement of voltage sensor 204 and current sensor 205, respectively. Similarly, at the other end of the transmission line 203 there may be arranged a fault detection device and possibly a protection system similar to or the same as the fault detection
10 device 220 and protection system 210. The operation of fault detection device and/or the protection system with respect to the circuit breaker 209 may be similar to or the same as the operation of the fault detection device 220 and protection system 210, respectively, with respect to the circuit breaker 208 such as described in the foregoing. In other words, even though Fig. 2
15 indicates sensing of current and voltage in the transmission line 203 only at one end of the transmission line 203 for purpose of fault detection, it is to be understood that this is merely for illustrating principles of the embodiments of the present invention and should not be considered as limiting. Rather, it is to be understood that that such sensing of current and voltage can be
20 implemented at both ends of the transmission line 203 so as to facilitate or even enable fault detection in the transmission line 203 at both ends of the transmission line 203, where the fault detection operating principles in both ends of the transmission line 203 are similar or the same.

It is to be understood that the circuit representation in Fig. 2 which
25 illustrates a section of the power system 200 is schematic and not drawn to scale. For example, although in Fig. 2 the distance between the ends of the transmission line 203, e.g. the distance between voltage sensor 204 and/or current sensor 205 and circuit breaker 209, might appear small, the transmission line 203 may be arranged such that the distance is relatively
30 large, e.g. between 500 km and 1000 km.

Referring now to Fig. 3 there is shown a circuit representation that illustrates a section of a power system 200 exemplified by a multi-terminal High Voltage Direct Current (HVDC) grid 200, in accordance with another embodiment of the present invention. The embodiment depicted in Fig. 3
35 differs from the embodiment depicted in Fig. 2 by the fault detection device 220 being integrally arranged in the protection system 210. Like numbers refer to like or similar elements or components in Figs. 2 and 3. In Fig. 3, the

processing unit 222 is adapted to, on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is a fault F1, e.g. a permanent fault, in the transmission line 203, which generated signal or a signal derived
5 based on the generated signal may be transmitted to the circuit breaker 208, as indicated by reference numeral 226 in Fig. 3.

It is to be noted that although Figs. 2 and 3 indicate the situation where principles of embodiments of the present invention are implemented at one terminal or terminal station only to which the transmission line 203 is
10 connected, this is not to be seen as limiting. Rather, principles of embodiments of the present invention such as described with reference to Fig. 2 or 3 can be implemented at a selected number of terminals or terminal stations included in the power system 200, or even at each terminal or terminal station included in the power system 200.

15 After a circuit breaker 208 at one terminal has auto reclosed, another terminal, e.g. the one on the right-hand side in Fig. 2 or 3, could check a voltage of the transmission line 203, e.g. a voltage between the transmission line 203 and ground, in order to determine if a fault persists in the transmission line 203. On a condition that the voltage check confirms that
20 there is a fault persisting, the circuit breaker 209 may be blocked or prevented from auto reclosing. No communication, e.g. signalling or communication of data and/or instructions, between the terminals may be required. The voltage check may for example include comparing the voltage with a certain threshold value. In case the voltage falls below the threshold value an auto reclosing
25 signal (cf. Figs. 5-7 and 11) is blocked, since a relatively low voltage could be an indication of a permanent fault. The above-described example of implementation of auto reclosing of the circuit breakers 208, 209 at both ends of the transmission line 203 is illustrated in Fig. 13, which shows a circuit representation that illustrates a section of a power system 200 exemplified by
30 a multi-terminal High Voltage Direct Current (HVDC) grid 200, in accordance with an embodiment of the present invention.

According to the embodiment depicted in Fig. 13, the protected unit 203 includes a transmission line 203, here exemplified by a DC OHL 203. The protected unit 203, which in the following will mostly be referred to as
35 transmission line 203, interconnects buses 201 and 202. A voltage sensor 204 and a current sensor 205 are arranged on the line side at one end of the transmission line 203. A voltage sensor 234 and a current sensor 235 are

arranged on the line side at the other end of the transmission line 203. The currents through the transmission line 203 in the respective ends of the transmission line 203 are measured by the current sensors 205 and 235, respectively, and the voltages in the respective ends of the transmission line 203 between the transmission line 203 and ground are measured by the voltage sensors 204 and 234, respectively. The transmission line 203 can be selectively disconnected or isolated from at least a portion of the rest of the power system or HVDC grid 200, and the transmission line 203 can be selectively connected to the at least a portion of the rest of the power system 200, e.g. after the transmission line 203 has been isolated from the at least a portion of the rest of the power system 200, by means of opening, or tripping, and/or closing at least one of circuit breakers 208, 209. For example, the circuit breakers 208, 209 can be tripped following a fault F1 on the transmission line 203 and then auto reclosed after a certain period of time. When the circuit breakers 208, 209 auto reclose, converters 206, 207 can provide grid voltage in the transmission line 203.

The section of the HVDC grid 200 comprises a first fault protection and/or detection system 241 and a second fault protection and/or detection system 242. Each of the first fault protection and/or detection system 241 and the second fault protection and/or detection system 242 may include a fault detection device and possibly a protection system e.g. similar to or the same as the fault detection device 220 and protection system 210 described above with reference to Fig. 2 or 3.

It is to be understood that any possible couplings between the fault detection device and possibly the protection system, and between the fault detection device and/or the protection system and the current sensor 205, 235, the voltage sensor 204, 234, and/or the circuit breaker 208, 209 for e.g. enabling communication of signals, messages, instructions and/or data between the respective elements, such as the couplings described above with reference to Fig. 2 or 3, are not shown in Fig. 13.

The circuit breaker 208 at one end of the transmission line 203 may be auto reclosed, e.g. upon receipt of signal 224 causing the circuit breaker 208 to auto reclose. If the circuit breaker 208 is successfully reclosed, e.g. if a temporary fault has disappeared since the opening of the circuit breaker 208, voltage may be restored at the other end of the transmission line 203. As illustrated in Fig. 13, after the circuit breaker 208 has auto reclosed, e.g. upon receipt of signal 224 causing the circuit breaker 208 to auto reclose, a voltage

V of the transmission line 203 at the other end of the transmission line 203 sensed by voltage sensor 234, e.g. a voltage between the transmission line 203 and ground, may be checked against a voltage threshold value V_{th} in order to determine if a fault persists in the transmission line 203. As indicated
5 in Fig. 13, the second fault protection and/or detection system 242 may be adapted to issue a signal 224 for causing the circuit breaker 209 to auto reclose. However, on a condition that the voltage check against the voltage threshold value V_{th} confirms that there is a fault persisting in the transmission line 203, e.g. on a condition that $V < V_{th}$ as indicated in Fig. 13, the circuit
10 breaker 209 may be blocked or prevented from auto reclosing. Otherwise, an auto reclosing signal 229 may be generated and transmitted to circuit breaker 209, causing it to auto reclose.

It is to be understood that the circuit representation in Fig. 13 which illustrates a section of the power system 200 is schematic and not drawn to
15 scale. For example, although in Fig. 13 the distance between the ends of the transmission line 203, or the distance between the current sensor 205 and the current sensor 235 or the distance between the voltage sensor 204 and the voltage sensor 234, might appear small, the transmission line 203 may be arranged such that the distance is relatively large, e.g. between 500 km and
20 1000 km.

Referring now to Fig. 4, there is shown a schematic flowchart of a method 300 according to an embodiment of the present invention for use in fault detection in a protected unit included in a power system, e.g. a
25 transmission line 203 included in the power system 200 described above with reference to Figs. 2, 3 or 13. The protected unit is adapted to convey power via at least one current path therein. The protected unit can be selectively disconnected from at least a portion of the rest of the power system and the protected unit can be selectively connected to the at least a portion of the rest of the power system.

30 The method 300 is for facilitating detection of any fault in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system. The method 300 comprises sensing a current in the at least one current path in the protected unit at one end thereof during a plurality of different time periods, thereby obtaining a plurality of sensed
35 currents, 301 .

Compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value is determined, 302.

5 It is checked whether at least one of the sensed currents comply with the respective first current criteria, 303.

On a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, a signal indicating that there is a fault in the protected unit is generated, 304.

10 Otherwise, i.e. on a condition that there is determined that none of the sensed currents comply with the respective first current criteria, a signal indicating that there is not a fault in the protected unit is generated, 305.

The method 300 may be implemented in a fault detection device 220 such as described above with reference to Figs. 2 or 3. The logic for facilitating detection of any fault in the protected unit after the protected unit 15 has been connected to the at least a portion of the rest of the power system, e.g. so as to decide whether to disconnect or isolate the protected unit from the at least a portion of the rest of the power system, will be described further with reference to Figs. 5-1 2, each of which is a logic diagram illustrating a method according to an embodiment of the present invention. Any one of the 20 methods illustrated in Figs. 5-1 2 may be implemented in a fault detection device 220 such as described above with reference to Fig. 2 or 3. The logic steps may for example be implemented in the processing unit 222 of a fault detection device 220 such as described above with reference to Fig. 2 or 3.

25 Referring now to Fig. 5, there is shown a logic diagram of a method according to an embodiment of the present invention that can be used to detect a permanent fault in the positive pole of a protected unit, which includes a bipolar HVDC transmission line, comprising a positive pole line, a negative pole line, and a metallic return line connected to ground. However, although Fig. 5 refers to the particular example of where the protected unit 30 includes a bipolar HVDC transmission line, the present invention is not limited to that particular example, which has also already been discussed in the foregoing. Rather, the example of where the protected unit includes a bipolar HVDC transmission line is taken as one non-limiting example for the purpose of describing principles of embodiments of the present invention.

35 The method illustrated in Fig. 5 can be used to detect a permanent fault in the positive pole of the transmission line after circuit breakers have reclosed in the positive pole transmission line. There are three inputs S1, S2

and S3, corresponding to values of DC current, DC voltage, and DC circuit breaker auto reclosing signals, respectively.

According to the embodiment depicted in Fig. 5, an auto reclosing protection function is activated by receiving auto reclosing signal S3, which for example may be issued by a transmission line protection system such as the protection system 210 described with reference to Fig. 2 or 3. The auto reclosing protection function may in alternative or in addition be activated by receiving circuit breaker closing signals and/or by detecting a relatively fast rise of the line side voltage. Thus, it may be possible to use a combination of two or more of the above-mentioned auto reclosing protection function activators in order to activate the auto reclosing protection function.

According to embodiments of the present invention a current in the at least one current path in the transmission line is sensed during a plurality of different time periods, thereby obtaining a plurality of sensed currents. This is represented in Fig. 5 by several current incremental elements i_1 , i_2 and i_3 , which accept current S1 as input and which are arranged for assessing whether a fault exists on the transmission line by comparing the plurality of sensed currents with a first current threshold value, "IncCurrThreshold". In the example depicted in Fig. 5 there are three current incremental elements but there may be only one current incremental element (described below with reference to e.g. Fig. 7) or two or four or more current incremental elements.

In the example depicted in Fig. 5 the current incremental elements i_1 , i_2 and i_3 evaluate the current values $I_{IncCurr1}(i_1-t_0)$, $H_{ncCurr2}(t_2-t_0)$ and $M_{ncCurr3}(t_3-t_0)$, respectively, and there can then be decided that a fault exists on the transmission line on a condition that $I_{IncCurr1}(t_1-t_0) > IncCurrThreshold$, $M_{ncCurr2}(i_2-t_0) > IncCurrThreshold$, or $M_{ncCurr3}(i_3-t_0) > IncCurrThreshold$, as evaluated by logical unit L1, being an "OR"-element.

In the current incremental elements i_1 , i_2 , i_3 , t_0 is the time when the auto reclosing protection function is activated, e.g. the time when auto reclosing signal S3 is received, t_1-t_0 is the 'time window' for the current incremental element i_1 , i.e. the time or instant at which the current $I_{IncCurr1}(t_1-t_0)$ is sampled, and t_2-t_0 and t_3-t_0 are the time windows for the current incremental elements i_2 and i_3 , respectively, i.e. the times or instants at which the currents $H_{ncCurr2}(t_2-t_0)$ and $M_{ncCurr3}(t_3-t_0)$ are sampled, respectively, where $t_3 > t_2 > t_1$. "IncCurrThreshold" is a positive value which may be predefined and higher than the value of a discharging or inrush current immediately following the transmission line having been reconnected to at

least a portion of the rest of the power system or relatively close to after the transmission line has been reconnected to at least a portion of the rest of the power system, e.g. immediately following auto reclosing of the circuit breakers or relatively close in time to after auto reclosing of the circuit
5 breakers.

The time or instant t_1-t_0 may be determined by a time for a fault current in the transmission line to reach a maximum discharging or inrush current immediately following the transmission line having been reconnected to at least a portion of the rest of the power system or relatively close in time to
10 after the transmission line has been reconnected to at least a portion of the rest of the power system, on a condition that the fault occurs at a terminal or terminal station to which the transmission line is connected. The time or instant t_2-t_0 may be determined by a time for a fault current in the transmission line to reach the first current threshold value, IncCurrThreshold, on a
15 condition that the fault occurs at a middle point of the transmission line. The time or instant t_3-t_0 may be determined by a time for a fault current in the transmission line to reach the first current threshold value, IncCurrThreshold, on a condition that the fault occurs at an end point of the transmission line.

An arrangement of current incremental elements I_1, I_2, I_3 as described
20 above may facilitate or even enable detection of 'close-in' faults following auto reclosing with speed faster than so called over-current protection schemes, and/or detection of any fault occurring over the whole or substantially the whole of the length of the transmission line, with relatively high speed and/or speed comparable to a speed of a primary protection system for detecting
25 faults in the transmission line.

According to embodiments of the present invention a voltage of the transmission line is sensed, and compliance of the sensed voltage with a voltage criteria based on a voltage threshold value is determined. This is represented in Fig. 5 by an overvoltage blocking element A2 which accepts
30 voltage S2 as input, and evaluates the absolute value of the voltage. The absolute value of the voltage is compared with a voltage threshold value, Vthreshold. When auto reclosing to a non-faulty transmission line, the line side voltage will initially 'jump' to rated line voltage and then oscillate about the rated line voltage, due to the nature of the RLC circuit. Eventually, this
35 voltage will reach or substantially reach the rated line voltage value when steady state conditions have been attained. As illustrated in Fig. 5, the auto reclosing protection function will be blocked for a predefined "DelayOff" time

once transient overvoltage is detected. Using such an overvoltage blocking element, the current incremental elements I_1 , I_2 , I_3 may use relatively sensitive settings.

It is possible that the output of the logical unit L1 might be false even though there is a fault in the transmission line, or in other words, that a fault present in the transmission line could not be detected by means of the current incremental elements I_1 , I_2 , I_3 . A back-up current module C2 may check if the absolute value of the current exceeds a threshold, $I_{Threshold}$. If that is the case, a signal indicative of that a fault is present in the transmission line may be generated after a predefined "DelayOn" time, provided the circuit breakers having auto reclosed prior to this condition being met and the transient overvoltage blocking element has not been activated. This signal is input into logical unit L2, being an "OR"-element. The output signal from the logical unit L1 is also input into logical unit L2, as illustrated in Fig. 5.

According to the embodiment depicted in Fig. 5, the signal generated by the overvoltage blocking element branch, the signal output from logical unit L2, and the auto reclosing signal S3 are all input into logical unit L3, being an "AND" element. In case the logical unit L3 determines a true condition a "Trip" signal, or disconnection signal, is issued to effect tripping or opening of the circuit breaker or circuit breakers.

It is to be noted that for the case of the negative pole of the transmission line, the values output from the current incremental elements I_1 , I_2 , I_3 will be negative following auto reclosing. Fig. 6 shows the slightly modified logic for the negative pole transmission line compared to the logic for positive pole transmission line illustrated in Fig. 5. In Fig. 6, the checks made in the C1 modules are based on a 'smaller than' threshold criteria, whereas in Fig. 5, the checks made in the C1 modules are based on a 'larger than' threshold criteria.

With reference to Figs. 5, 6, 8 and 9, any one of the C1, C2 and C3 modules may for example be hysteresis in nature or based on level comparator, as appropriate.

With reference to Figs. 7, 10, 11 and 12, any one of the C1 and C2 modules may for example be hysteresis in nature or based on level comparator, as appropriate.

For example, a reset value, IncCurrReset may be provided to the at least one of the C1 modules, which may facilitate or enable detection of

relatively high incremental currents before the incremental currents return to a normal, or nominal, level.

Referring now to Fig. 7, there is shown a logic diagram of a method according to an embodiment of the present invention that can be used to
5 detect a permanent fault in the positive pole of a protected unit, which includes a bipolar HVDC transmission line, comprising a positive pole line, a negative pole line, and a metallic return line connected to ground. However, although Fig. 7 refers to the particular example of where the protected unit includes a bipolar HVDC transmission line, the present invention is not limited
10 to that particular example, which has also already been discussed in the foregoing. Rather, the example of where the protected unit includes a bipolar HVDC transmission line is taken as one non-limiting example for the purpose of describing principles of embodiments of the present invention.

The method illustrated in Fig. 7 can be used to detect a permanent
15 fault in the positive pole of the transmission line after circuit breakers have reclosed in the positive pole transmission line. There are two inputs S1 and S2, corresponding to values of DC current and DC circuit breaker auto reclosing signals, respectively.

According to the embodiment depicted in Fig. 7, an auto reclosing
20 protection function is activated by receiving auto reclosing signal S2, which for example may be issued by a transmission line protection system such as the protection system 210 described with reference to Fig. 2 or 3. The auto reclosing protection function may in alternative or in addition be activated by receiving circuit breaker closing signals and/or by detecting a relatively fast
25 rise of the line side voltage. Thus, it may be possible to use a combination of two or more of the above-mentioned auto reclosing protection function activators in order to activate the auto reclosing protection function.

According to embodiments of the present invention a current in the transmission line is sensed continuously during a time window (M_0), where t_0
30 is a time at which the transmission line is connected to the at least a portion of the rest of the power system after having been disconnected from the at least a portion of the rest of the power system, e.g. the time when auto reclosing signal S2 is received, and t_1 is a time such that $t_1 > t_0$. This is represented in Fig. 7 by a differential value current element which accepts
35 current S1 as input and which is arranged to determine at least one quotient of a difference between currents $I(t_1)$ and $I(t_0)$, where t denotes time, and a difference between t and t_0 , i.e. a differential current value. The differential

current value or values are calculated or determined during the time window $(t_1 - t_0)$, e.g. at different times t , and are compared to a current slope threshold value "SlopeCurrThreshold", cf. module C 1, which current slope threshold value in this case constitutes the first current threshold value. The time
5 window $(t_1 - t_0)$ may for example be determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value, or current slope threshold value, on a condition that the fault occurs at an end point of the at least one current path in the protected unit.

The threshold value "SlopeCurrThreshold" may be a positive value
10 which can be determined based on the inrush current to the surge impedance of the faulted protected unit or transmission line and possibly taking into account a certain margin. According to an example of a transmission line being constituted by an OHL having a length of about 400 km, the surge impedance may be about 295 Ω and the inrush current about 1 kA. With a
15 margin of 0.5 kA, "SlopeCurrThreshold" may according to the example be about 1.5 kA. According to the example of a transmission line being constituted by an OHL having a length of about 400 km, the time window $(t_1 - t_0)$ may for example be about 4 ms.

The branch of the logic diagram in Fig. 7 including the current module
20 C2 is similar to or the same as the branch of the logical diagram in Fig. 5 or 6 which includes current module C2.

Hence, a back-up current, or Overcurrent', module C2 may check if the absolute value of the current exceeds a threshold, IThreshold. If that is the case, a signal indicative of that a fault is present in the transmission line may
25 be generated after a predefined time, indicated in Fig. 7 by "Timed On/Off', provided the circuit breakers have auto reclosed prior to this condition being met and the transient overvoltage blocking element has not been activated. This signal is input into logical unit L 1, being an "OR"-element, together with the output from module C 1, as illustrated in Fig. 7.

30 According to an example of a transmission line being constituted by an OHL having a length of about 400 km, the threshold IThreshold may for example be about 3.5 kA and the predefined time about 0.5 ms, or the threshold Ithreshold may be about 2 kA and the predefined time 2.5 ms.

Referring now to Figs. 8 and 10 and Fig. 9, respectively, there are
35 shown logic diagrams of methods according to embodiments of the present invention that can be used to detect a permanent fault in the positive and negative pole of a protected unit, respectively, which protected unit includes a

bipolar HVDC transmission line, comprising a positive pole line, a negative pole line, and a metallic return line connected to ground. However, although Figs. 8, 9 and 10 refer to the particular example of where the protected unit includes a bipolar HVDC transmission line, the present invention is not limited
5 to that particular example, which has also already been discussed in the foregoing. Rather, the example of where the protected unit includes a bipolar HVDC transmission line is taken as one non-limiting example for the purpose of describing principles of embodiments of the present invention.

The methods illustrated in Figs. 8 and 10 and in Fig. 9, respectively,
10 can be used to detect a permanent fault in the positive and negative pole of the transmission line, respectively, after switching a circuit breaker to energize the transmission line when it is open. The logic in the logic diagrams in Figs. 8, 9 and 10 differ from the logic diagrams in Figs. 5, 6 and 7, respectively, only in that instead of receiving an auto reclosing signal S3
15 (Figs. 5 and 6) or auto reclosing signal S2 (Fig. 7) a DC circuit breaker (DCCB) Switch On Status signal S3 (Figs. 8 and 9) or a DCCB Switch On Status signal S2 (Fig. 10) is received. The DCCB Switch On Status signal may be received from a DC circuit breaker after energization of the transmission line. The rest of the logic in the logic diagrams in Figs. 8, 9 and
20 10 is similar to or the same as the logic in the logic diagrams in Figs. 5, 6 and 7, respectively.

The DCCB Switch On Status signal S3 (Figs. 8 and 9) or DCCB Switch On Status signal S2 (Fig. 10) can indicate a change in switch status of the circuit breaker from open to closed, or vice versa.

25 With further reference to Figs. 7 and 10, it is to be noted that for the case of the negative pole of the transmission line, the differential current values input into module C1 will be negative following auto reclosing. Figs. 11 and 12 show the slightly modified logic for the negative pole transmission line compared to the logic for positive pole transmission line illustrated in Figs. 7
30 and 10, respectively. In Figs. 11 and 12, the checks made in the C1 modules are based on a 'smaller than' threshold criteria, whereas in Figs. 7 and 10, the checks made in the C1 modules are based on a 'larger than' threshold criteria.

In conclusion, there is disclosed a method for use in fault detection in a
35 protected unit included in a power system. The method may facilitate detection of any fault in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system. A current

in the at least one current path in the protected unit is sensed during a plurality of different time periods, thereby obtaining a plurality of sensed currents. The current in the at least one current path may be sensed at one end of the protected unit. Compliance of at least one of the sensed currents
5 with a respective first current criteria is determined based on a first current threshold value. On a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, a signal may be generated indicating that there is a fault in the protected unit. On a
10 condition that there is determined that none of the sensed currents comply with the respective first current criteria, a signal may be generated indicating that there is not a fault in the protected unit.

While the present invention has been illustrated and described in detail in the appended drawings and the foregoing description, such illustration and description are to be considered illustrative or exemplifying and not restrictive;
15 the present invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate
20 that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS

1. A method (300) for use in fault detection in a protected unit (203) included in a power system (200), the protected unit being adapted to convey
5 power via at least one current path therein, wherein the protected unit can be selectively disconnected from at least a portion of the rest of the power system and the protected unit can be selectively connected to the at least a portion of the rest of the power system, the method being for facilitating detection of any fault (F1) in the protected unit after the protected unit has
10 been connected to the at least a portion of the rest of the power system, the method comprising:
- sensing (301) a current in the at least one current path in the protected unit at one end thereof during a plurality of different time periods, thereby obtaining a plurality of sensed currents;
 - 15 determining (302) compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value; on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, generating (304) a signal indicating that there is a fault in the protected unit; and
20 on a condition that there is determined that none of the sensed currents comply with the respective first current criteria, generating (305) a signal indicating that there is not a fault in the protected unit.
2. A method according to claim 1, further comprising:
- 25 determining an absolute value of at least one of the sensed currents; determining compliance of the absolute value with a second current criteria based on a second current threshold value; on a condition that there is determined that the absolute value complies with the second current criteria, generating a signal indicating that
30 there is a fault in the protected unit; and on a condition that there is determined that the absolute value complies with the second current criteria, generating a signal indicating that there is not a fault in the protected unit.
3. A method according to claim 1 or 2, further comprising:
- 35 sensing a voltage of the at least one current path in the protected unit at one end thereof;

determining compliance of the sensed voltage with a voltage criteria based on a voltage threshold value;

on a condition that there is determined that the sensed voltage complies with the voltage criteria, generating a signal indicating that there is a
5 fault in the protected unit; and

on a condition that there is determined that the sensed voltage complies with the voltage criteria, generating a signal indicating that there is not a fault in the protected unit.

10 4. A method according to claim 1 or 2, further comprising:

on a condition that at least one of the generated signal or signals indicates that there is a fault in the protected unit, generating a first derived signal indicating that there is a fault in the protected unit; and

15 on a condition that none of the generated signal or signals indicate that there is a fault in the protected unit, generating a first derived signal indicating that there is not a fault in the protected unit.

5. A method according to claim 4, further comprising:

20 sensing a voltage of the at least one current path in the protected unit at one end thereof;

determining compliance of the sensed voltage with a voltage criteria based on a voltage threshold value;

25 on a condition that there is determined that the sensed voltage complies with the voltage criteria, generating a signal indicating that there is a fault in the protected unit;

on a condition that there is determined that the sensed voltage complies with the voltage criteria, generating a signal indicating that there is not a fault in the protected unit;

30 on a condition that both of said generated signal and the first derived signal indicate that there is a fault in the protected unit, generating a second derived signal indicating that there is a fault in the protected unit; and

on a condition that both of said generated signal and the first derived signal indicate that there is not a fault in the protected unit, generating a second derived signal indicating that there is not a fault in the protected unit.

35

6. A method according to any one of claims 1-5, wherein a current in the at least one current path in the protected unit is sensed during at least three

different respective time instants (M_0) , $(t_2 - t_0)$, (M_0) , where t_0 is a time at which the protected unit is connected to the at least a portion of the rest of the power system after having been disconnected from the at least a portion of the rest of the power system, and $t_3 > t_2 > t_1 > t_0$, thereby obtaining at least
 5 three sensed currents $I(t_1 - t_0)$, $I(t_2 - t_0)$, and $I(t_3 - t_0)$.

7. A method according to claim 6, wherein $(t_1 - k)$ is determined by a time for a fault current in the at least one current path in the protected unit to reach a maximum discharging or inrush current subsequent to the protected unit
 10 having been connected to the at least a portion of the rest of the power system after having been disconnected from the at least a portion of the rest of the power system, on a condition that the fault occurs at a terminal to which the protected unit is connected.

15 8. A method according to claim 6 or 7, wherein $(t_2 - b)$ is determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value on a condition that the fault occurs at a middle point of the at least one current path in the protected unit.

20 9. A method according to any one of claims 6-8, wherein $(t_3 - b)$ is determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value on a condition that the fault occurs at an end point of the at least one current path in the protected unit.

25

10. A method according to claim 1, wherein a current in the at least one current path in the protected unit is sensed continuously during a time window $(t_1 - t_0)$, where t_0 is a time at which the protected unit is connected to the at least a portion of the rest of the power system after having been disconnected
 30 from the at least a portion of the rest of the power system, and t_1 is a time such that $t_1 > t_0$;

wherein determining compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value comprises:

35 determining at least one quotient of a difference between currents $I(t > t_0)$ and $I(t_0)$, where t denotes time, and a difference between t and t_0 ; and

comparing the determined at least one quotient during the time window $(t_1 - t_0)$ with a current slope threshold value, the current slope threshold value constituting the first current threshold value.

- 5 11. A method according to claim 10, wherein $(t_1 - t_0)$ is determined by a time for a fault current in the at least one current path in the protected unit to reach the first current threshold value on a condition that the fault occurs at an end point of the at least one current path in the protected unit.
- 10 12. A fault detection device (220) for detection of a fault in a protected unit (203) included in a power system (200), the protected unit being adapted to convey power via at least one current path therein, wherein the protected unit can be selectively disconnected from at least a portion of the rest of the power system and the protected unit can be selectively connected to the at
15 least a portion of the rest of the power system, wherein the fault detection device is adapted to facilitate detection of any fault (F1) in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system, the fault detection device comprising:
a current sensor unit (205) adapted to sense a current in the at least
20 one current path in the protected unit at one end thereof during a plurality of different time periods, thereby obtaining a plurality of sensed currents;
a processing unit (222) coupled to the current sensor unit and adapted to:
determine compliance of at least one of the sensed currents with
25 a respective first current criteria based on a first current threshold value;
on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria,
generate a signal indicating that there is a fault in the protected unit;
30 and
on a condition that there is determined that none of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is not a fault in the protected unit.
- 35 13. A fault detection device according to claim 12, wherein the processing unit is further adapted to:
determine the absolute value of at least one of the sensed currents;

determine compliance of the absolute value with a second current criteria based on a second current threshold value;

on a condition that there is determined that absolute value complies with the second current criteria, generate a signal indicating that there is a
5 fault in the protected unit; and

on a condition that there is determined that the absolute value complies with the second current criteria, generate a signal indicating that there is not a fault in the protected unit.

10 14. A fault detection device according to claim 12 or 13, further comprising:
a voltage sensor unit (204) adapted to sense a voltage of the at least one current path in the protected unit at one end thereof;

wherein the voltage sensor unit is coupled to the processing unit; and wherein the processing unit is further adapted to:

15 determine compliance of the sensed voltage with a voltage criteria based on a voltage threshold value;

on a condition that there is determined that the sensed voltage complies with the voltage criteria, generate a signal indicating that there is a fault in the protected unit; and

20 on a condition that there is determined that sensed voltage complies with the voltage criteria, generate a signal indicating that there is not a fault in the protected unit.

15. A power system (200) including:

25 a protected unit (203) adapted to convey power via at least one current path therein, wherein the protected unit can be selectively disconnected from at least a portion of the rest of the power system and the protected unit can be selectively connected to the at least a portion of the rest of the power system; and

30 a fault detection device (220) according to any one of claims 12-14 adapted to facilitate detection of any fault (F1) in the protected unit after the protected unit has been connected to the at least a portion of the rest of the power system.

35 16. A power system according to claim 15, further including:

at least one DC circuit breaker (208, 209) adapted to selectively disconnect the protected unit from the at least a portion of the rest of the

power system upon receipt of a disconnection signal and selectively connect the protected unit to the at least a portion of the rest of the power system upon receipt of a connection signal;

5 wherein the fault detection device is communicatively coupled to the at least one DC circuit breaker; and

wherein the processing unit (222) of the fault detection device is adapted to, on a condition that at least one of the generated signals indicate that there is a fault in the protected unit, generate a disconnection signal and transmit the disconnection signal to the at least one DC circuit breaker,
10 whereby the protected unit becomes disconnected from the at least a portion of the rest of the power system.

17. A power system according to claim 15 or 16, wherein the protected unit comprises a power transmission line.

15

18. A power system according to claim 17, wherein the power transmission line comprises a direct current, DC, power transmission line.

19. A power system according to claim 17 or 18, wherein the power transmission line comprises an overhead line.

20

20. A power system according to any one of claims 15-19, wherein the power system comprises a High Voltage Direct Current, HVDC, power transmission system.

25

21. A computer program product adapted to be executed in a processing unit (222) of a fault detection device (220) in a power system (200), the computer program product comprising computer-readable means carrying computer program code, the power system including a protected unit (203)
30 that can be selectively isolated from at least a portion of the rest of the power system and the protected unit can be selectively re-connected to the at least a portion of the rest of the power system after having been isolated from the at least a portion of the rest of the power system, wherein the fault detection device is adapted to facilitate detection of any fault (F1) in the protected unit
35 after the protected unit has been re-connected to the at least a portion of the rest of the power system after having been isolated from the at least a portion of the rest of the power system, the fault detection device comprising a

current sensor unit (205) coupled to the processing unit and adapted to sense a current in the at least one current path in the protected unit at one end thereof at least once, the computer program code being configured to, when executed in the processing unit of the fault detection device:

- 5 cause the current sensor unit to sense a current in the at least one current path in the protected unit at one end thereof during a plurality of different time periods, thereby obtaining a plurality of sensed currents;
 determine compliance of at least one of the sensed currents with a respective first current criteria based on a first current threshold value;
- 10 on a condition that there is determined that at least one of the sensed currents comply with the respective first current criteria, generate a signal indicating that there is a fault in the protected unit; and
 on a condition that there is determined that none of the sensed currents comply with the respective first current criteria, generate a signal
- 15 indicating that there is not a fault in the protected unit.

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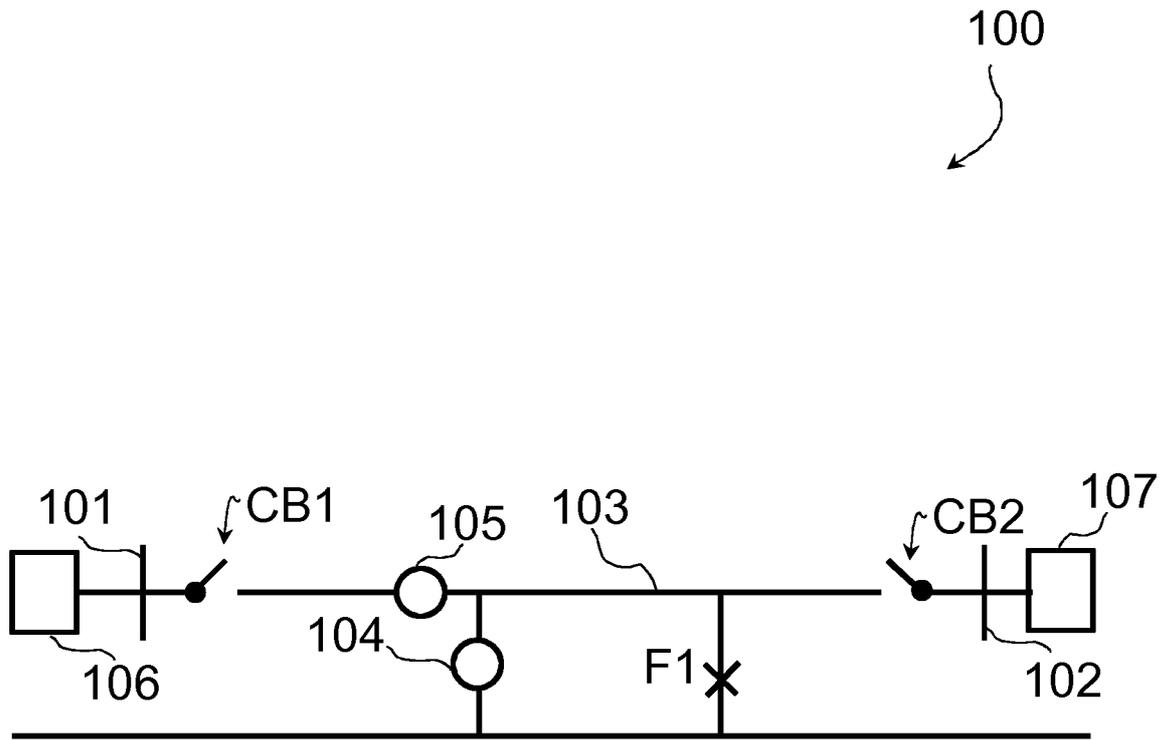


Fig. 1

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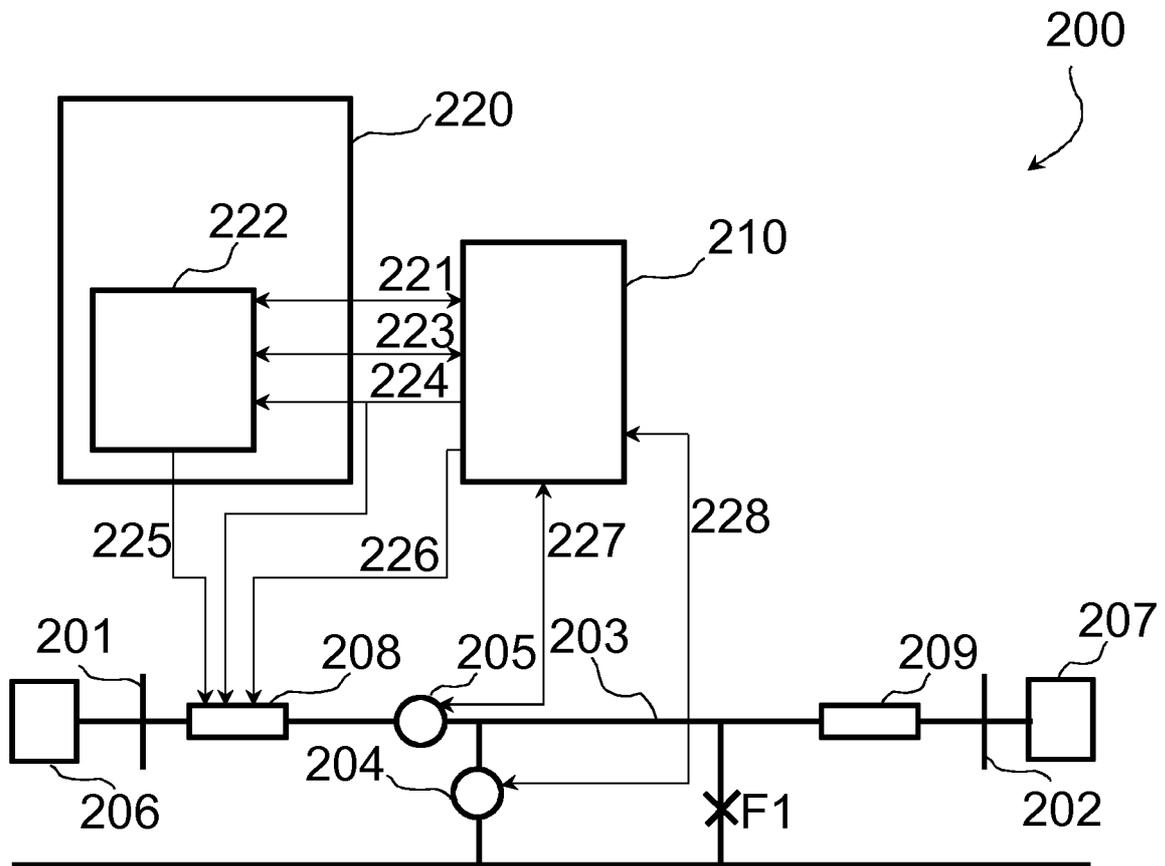


Fig. 2

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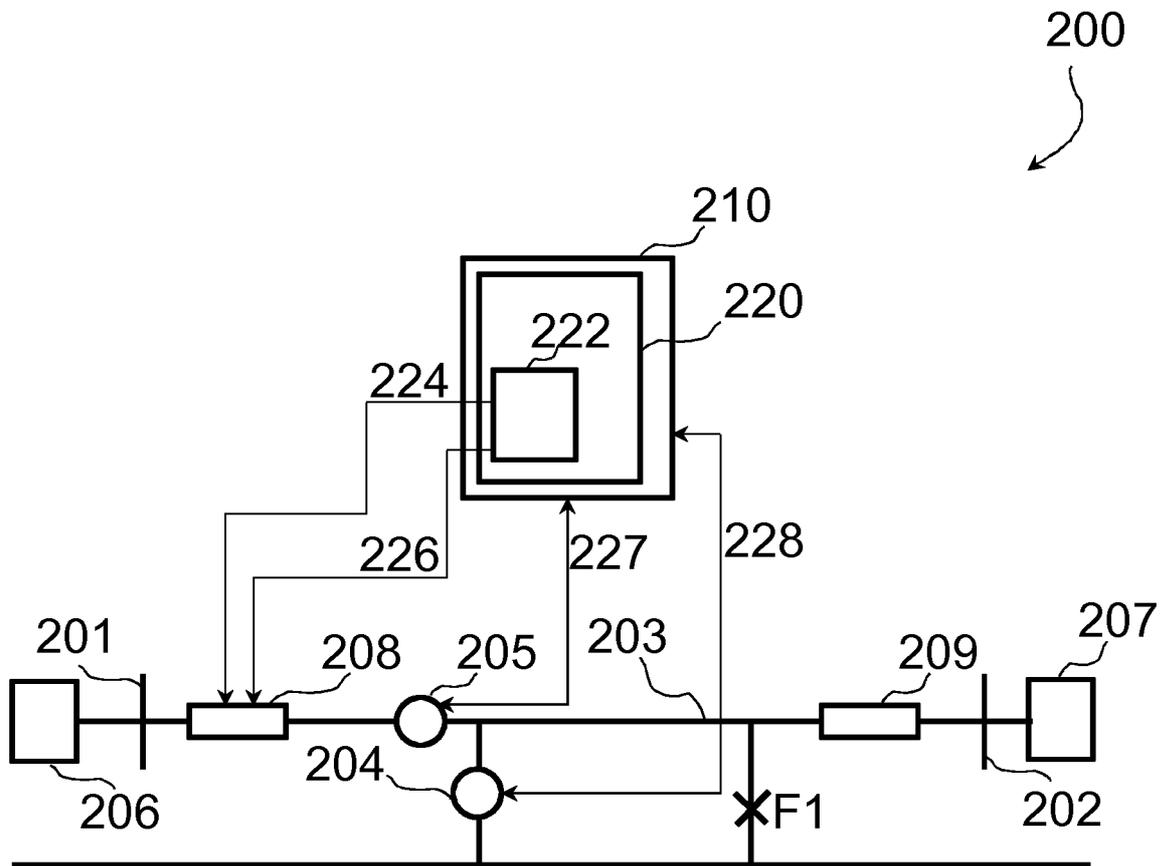


Fig. 3

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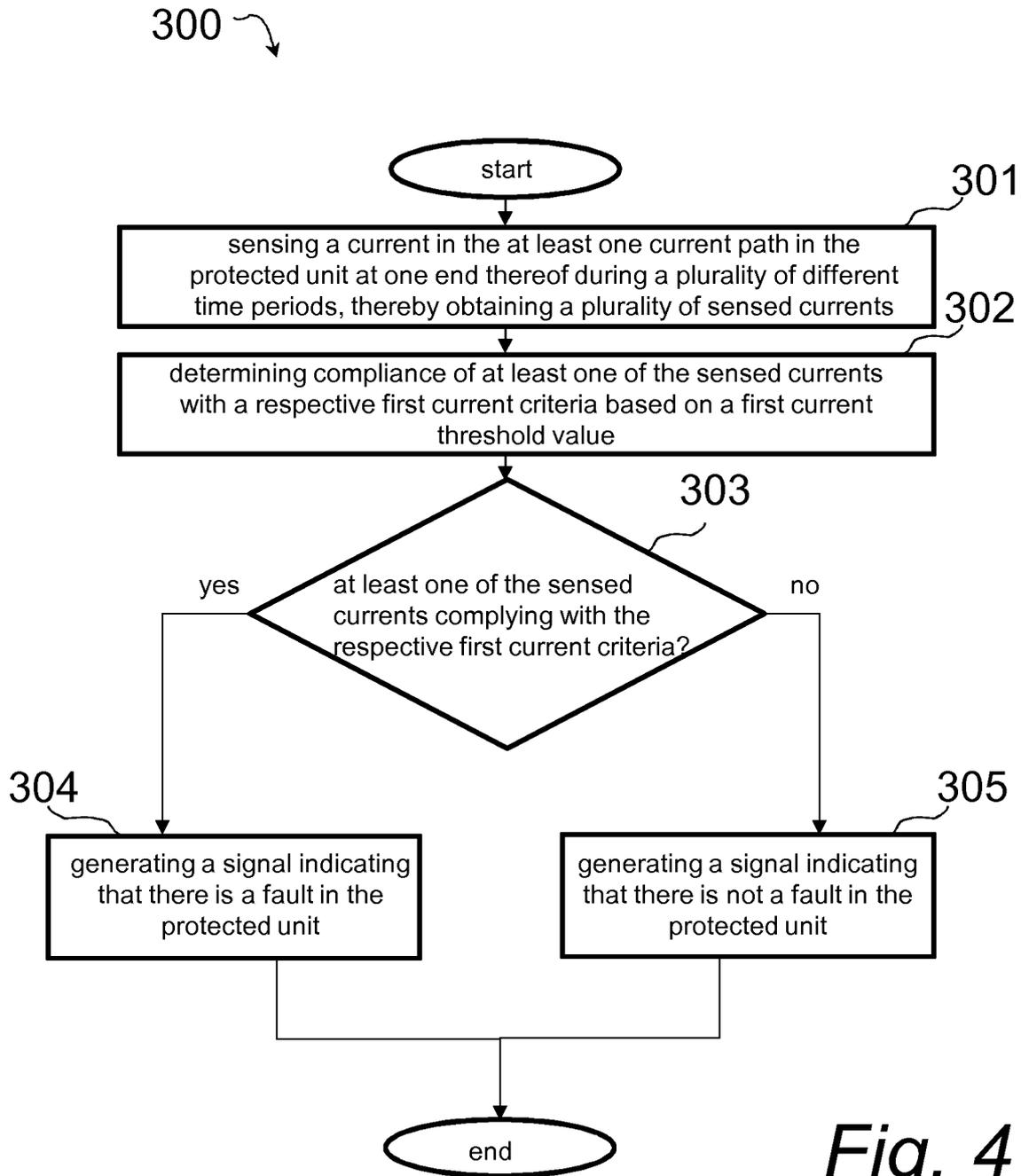


Fig. 4

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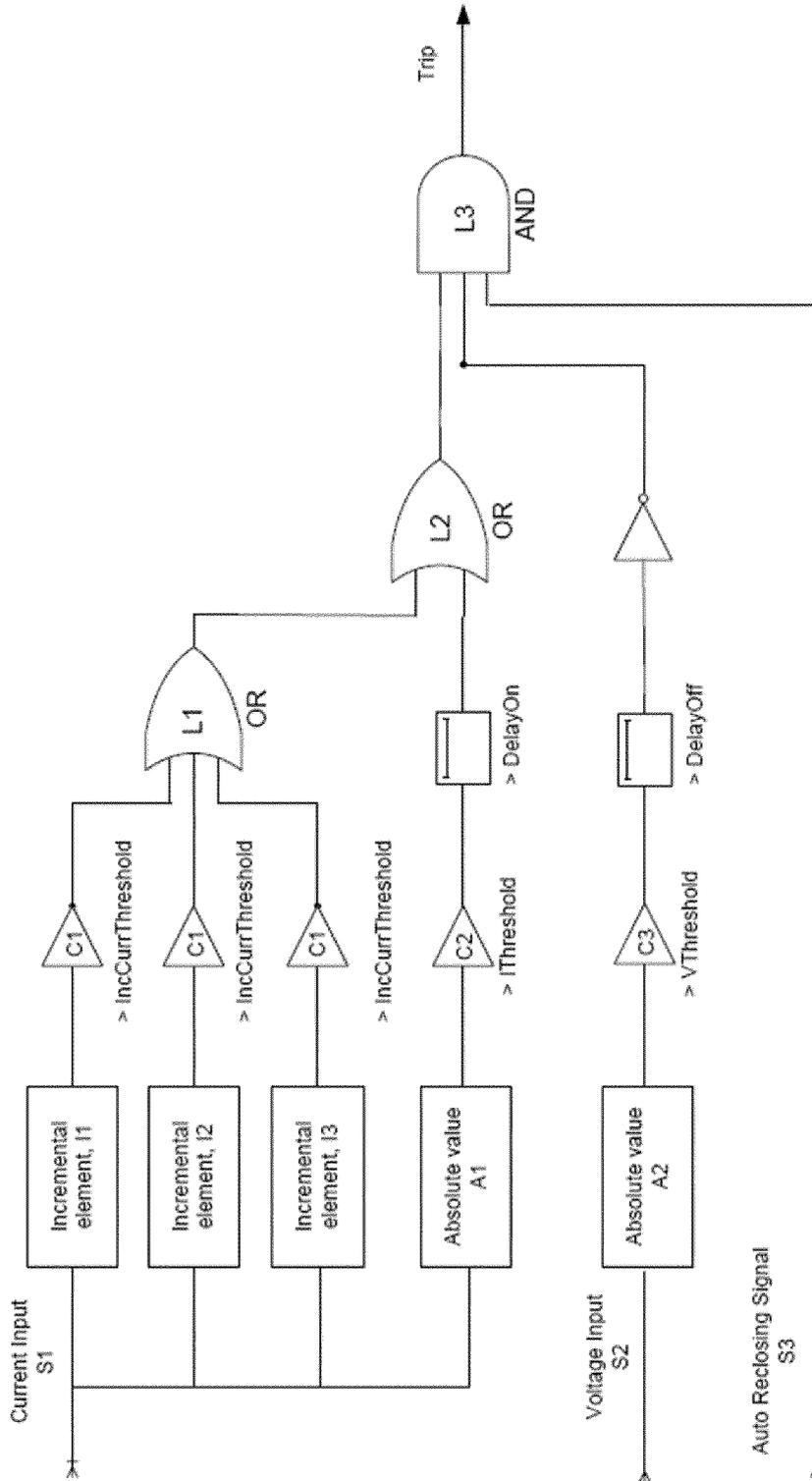


Fig. 5

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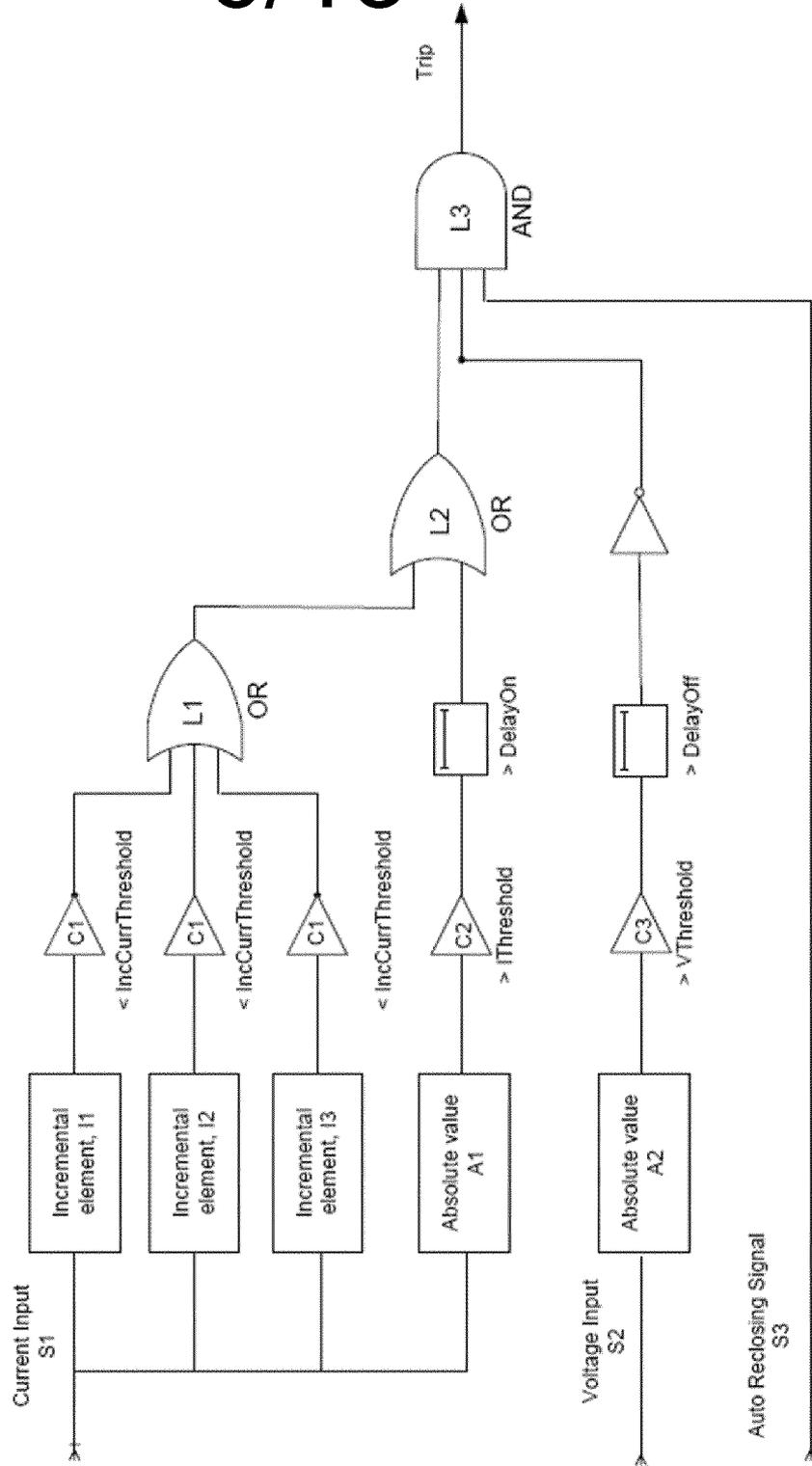


Fig. 6

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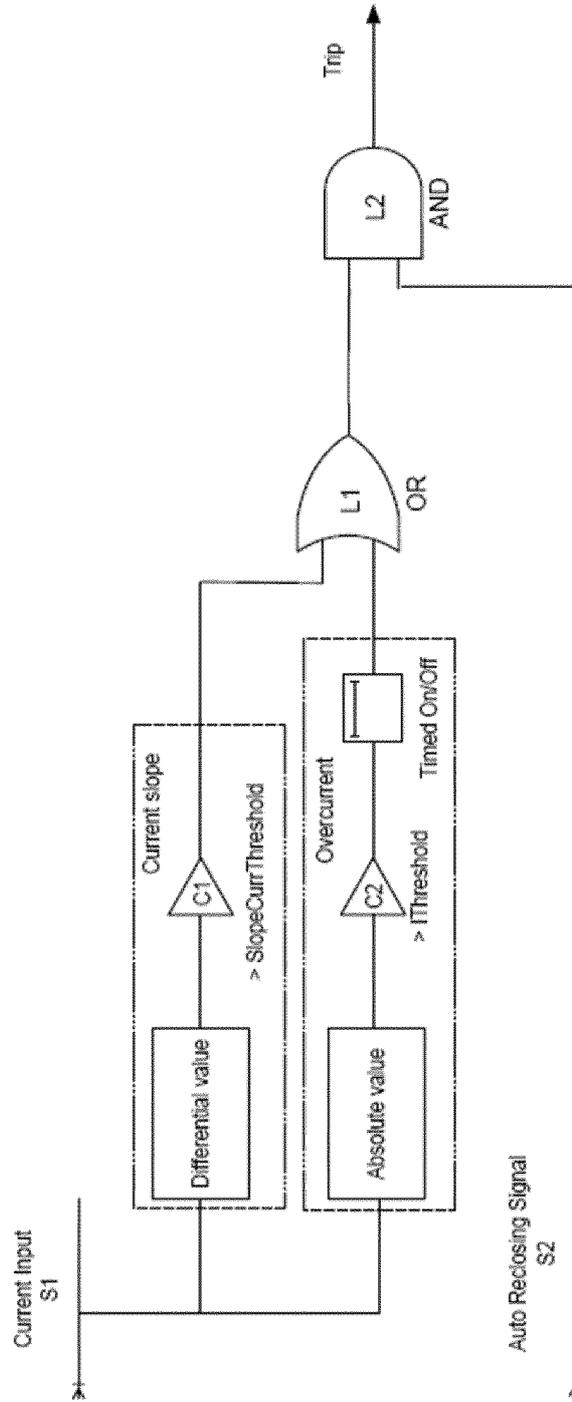


Fig. 7

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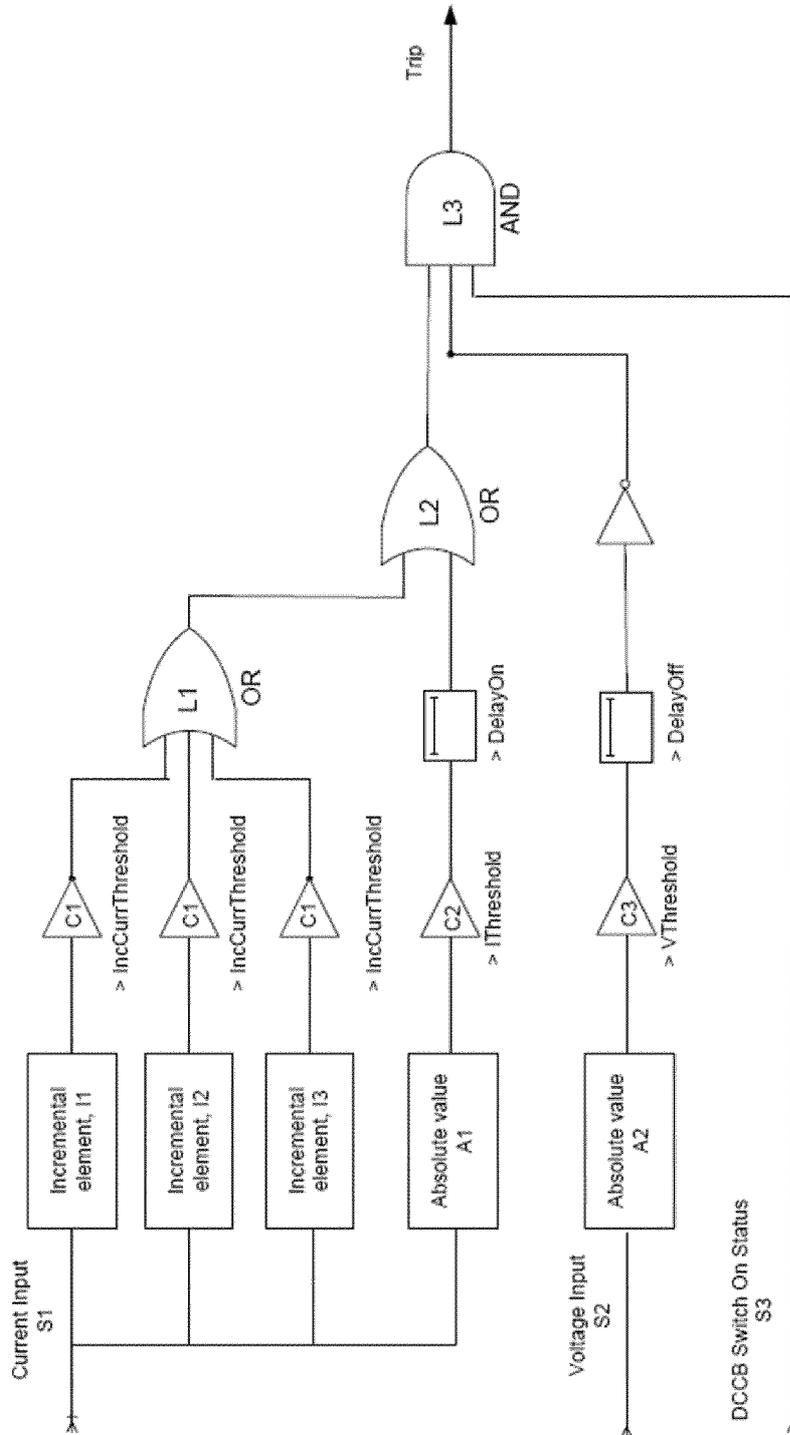


Fig. 8

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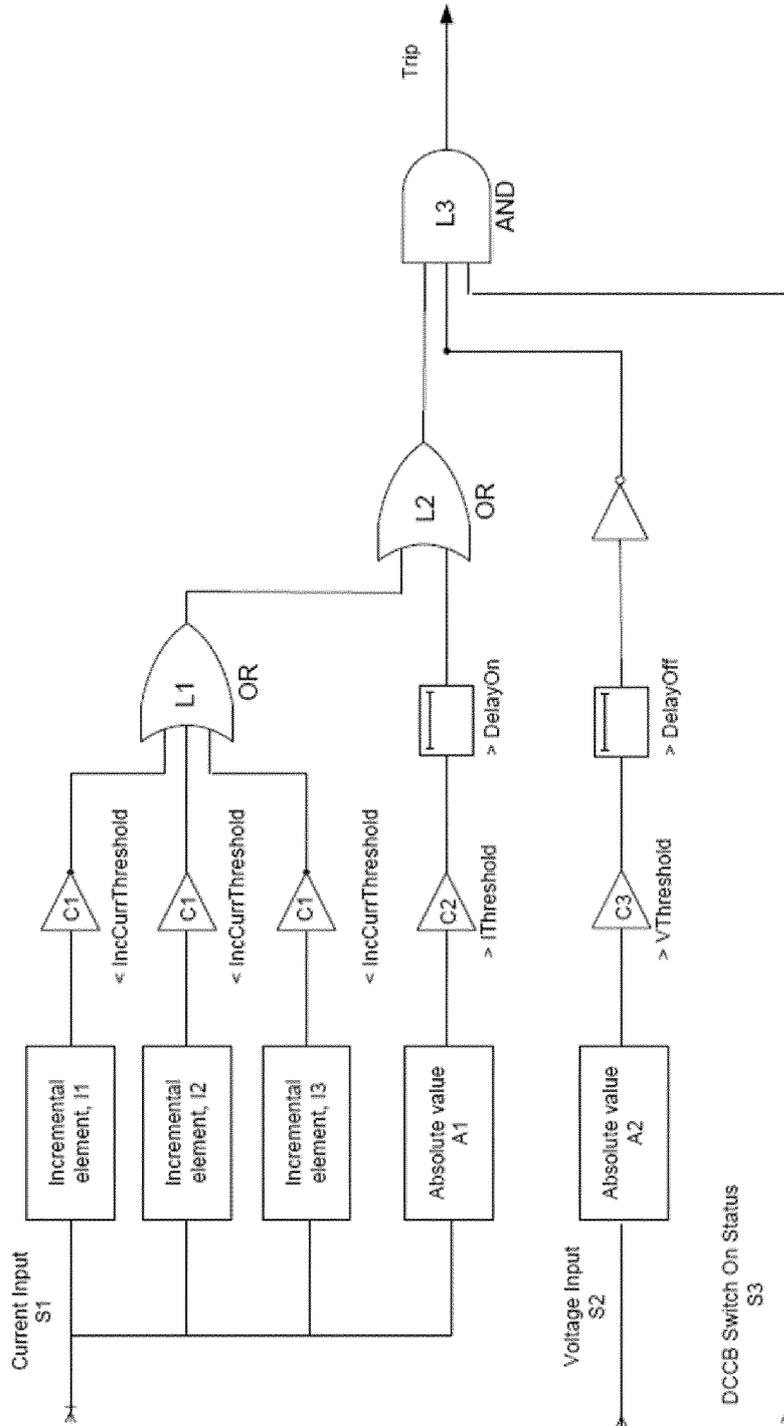


Fig. 9

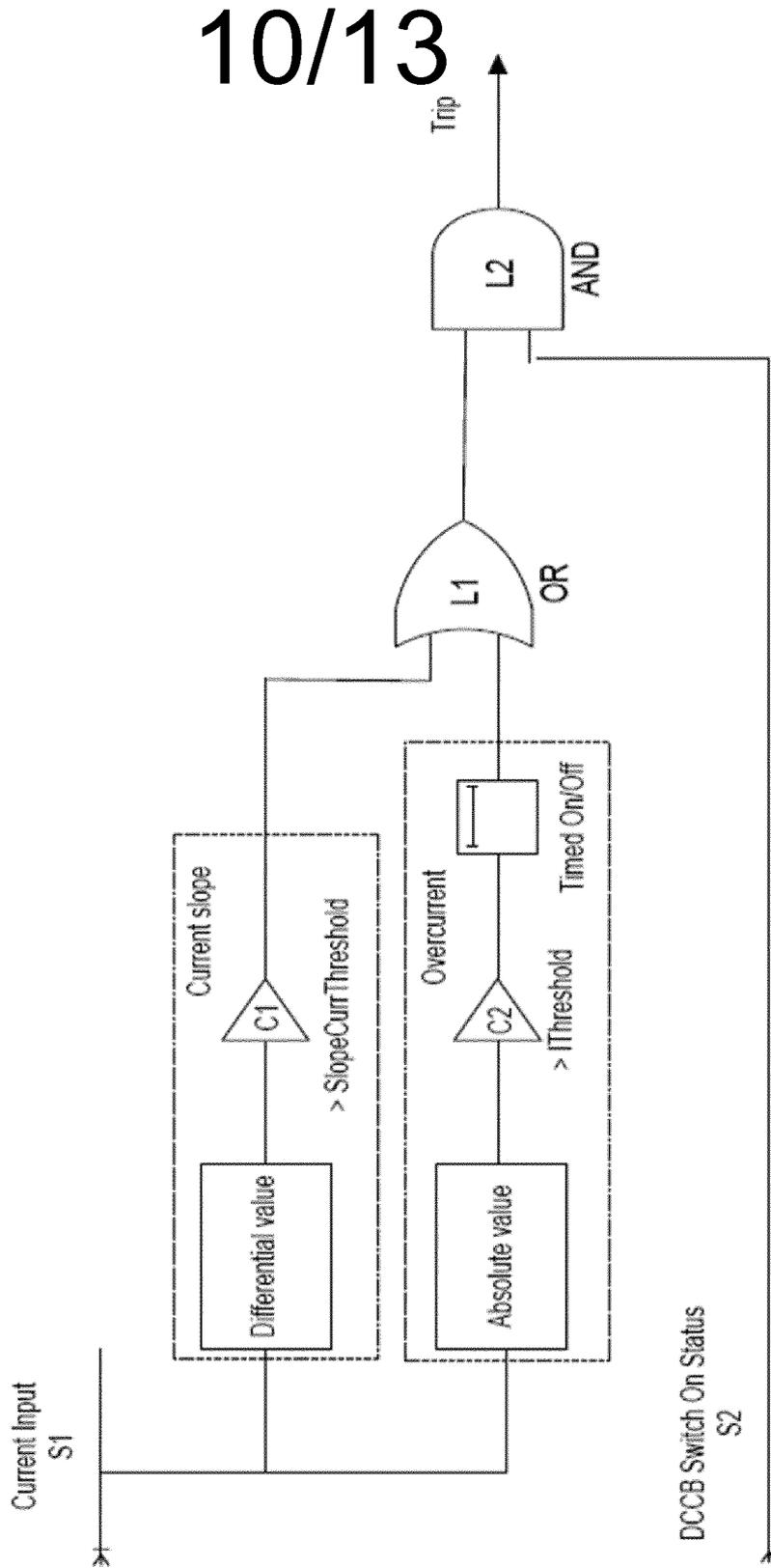


Fig. 10

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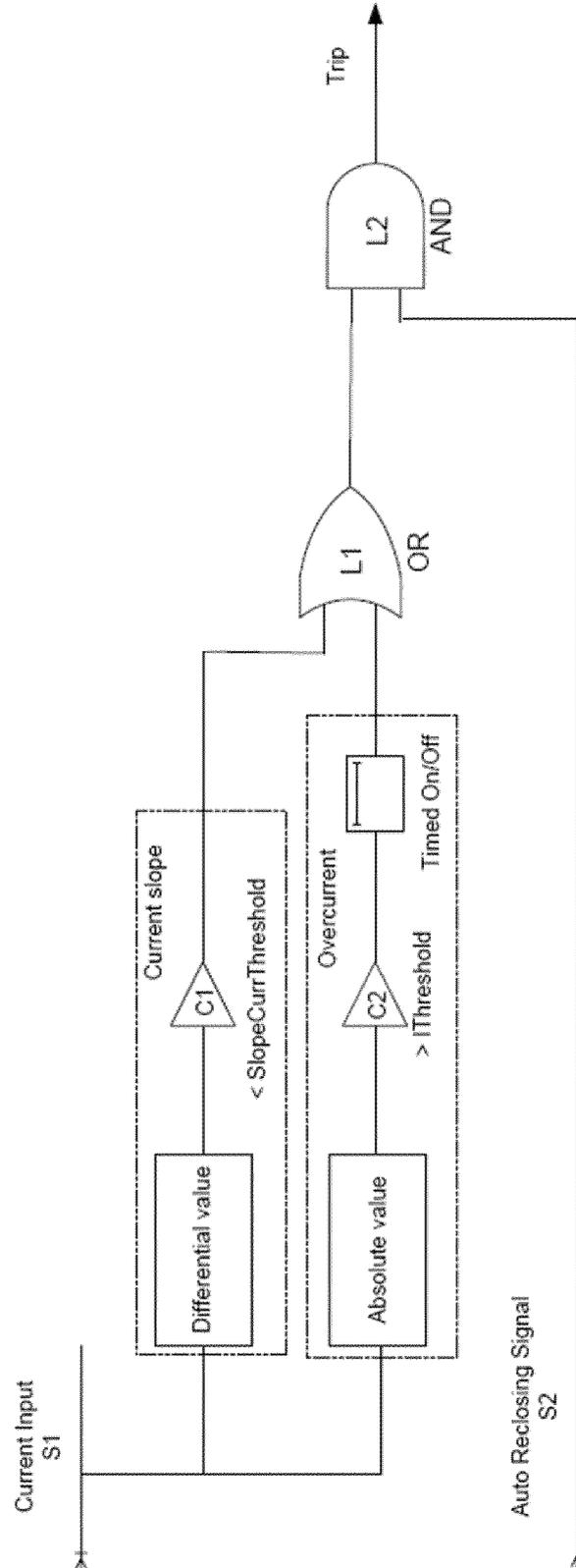


Fig. 11

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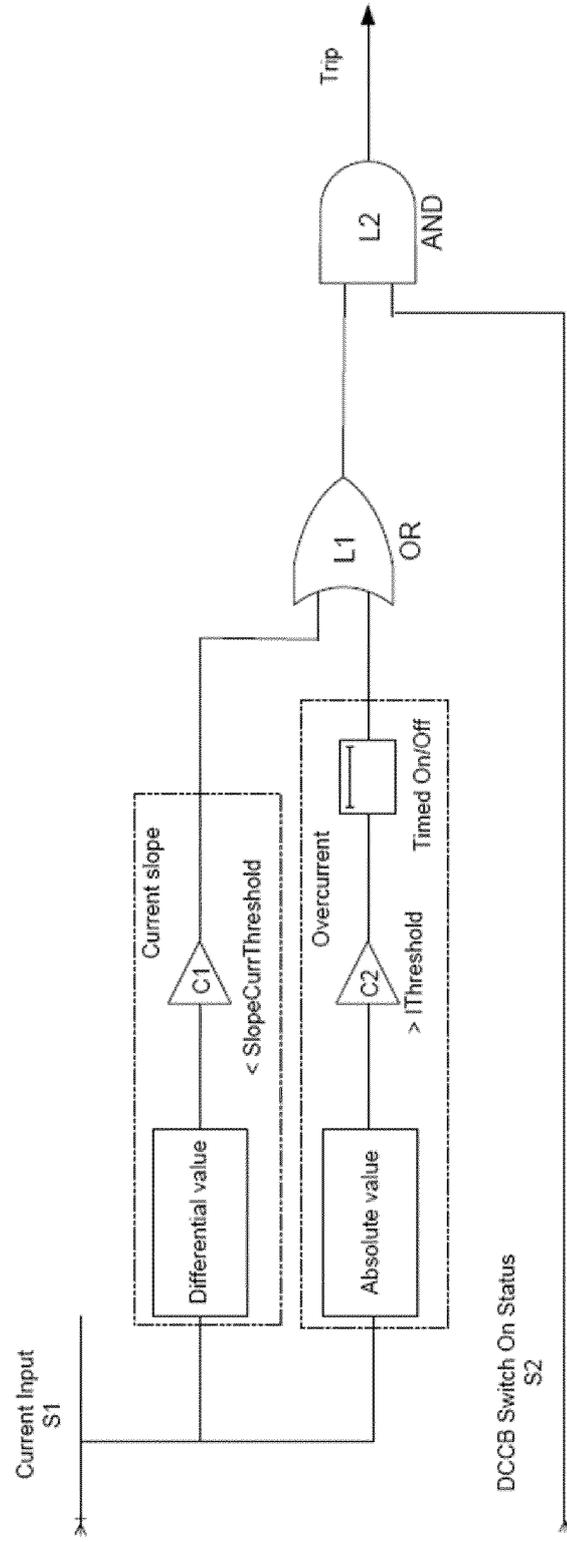


Fig. 12

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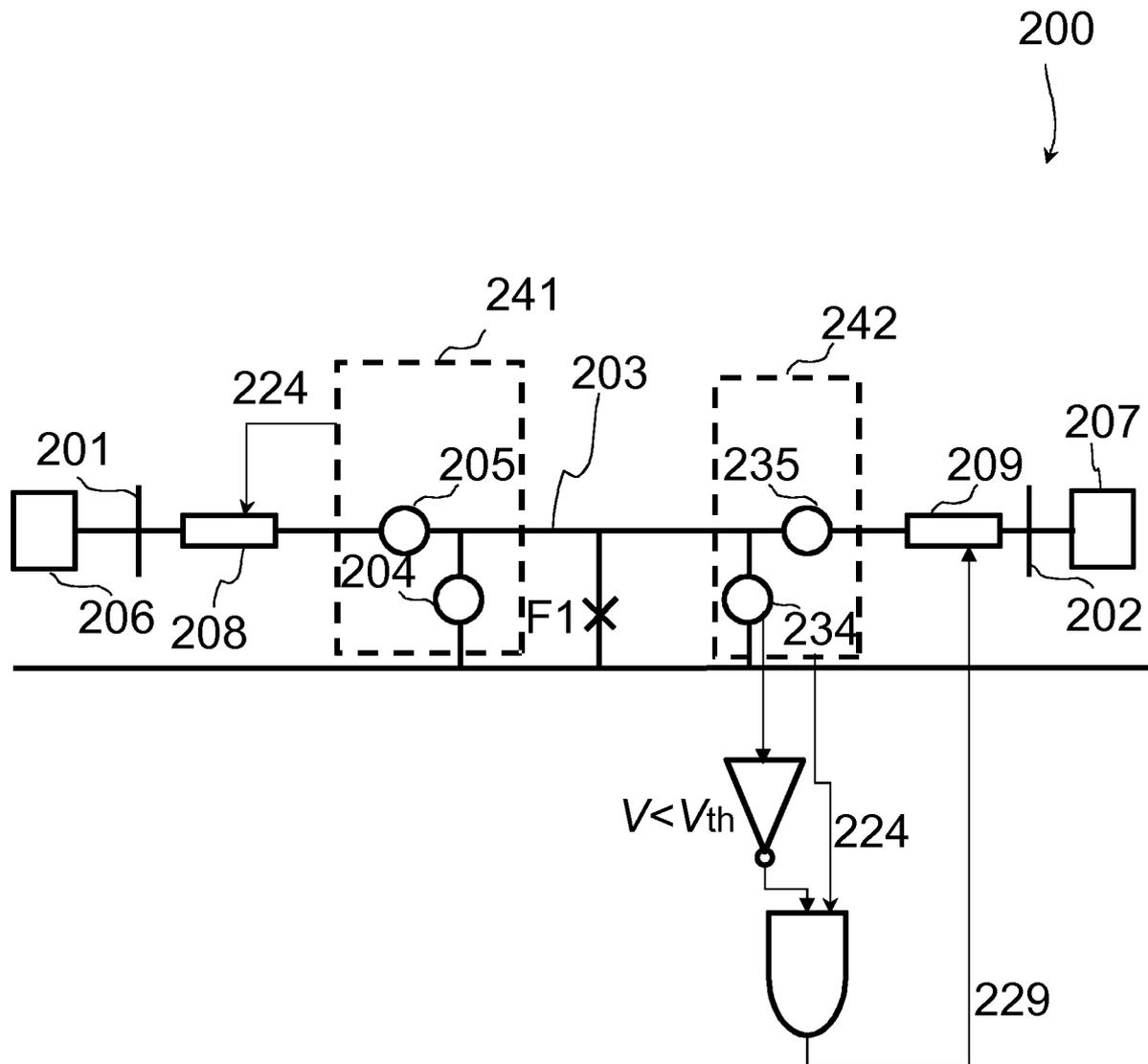


Fig. 13

INTERNATIONAL SEARCH REPORT

International application No PCT/EP2013/052760

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H02H3/087 G01R31/02 H02H7/26
 ADD.

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)
 H02H G01R

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NAIDOO D ET AL: "HVDC line protection for the proposed future HVDC systems", POWER SYSTEM TECHNOLOGY, 2004. POWERCON 2004. 2004 INTERNATIONAL CONFERENCE ON SINGAPORE 21-24 NOV. 2004, PISCATAWAY, NJ, USA, IEEE, US, vol. 2, 21 November 2004 (2004-11-21), page 1327, XP010811476, DOI: 10.1109/ICPST.2004.1460207 ISBN: 978-0-7803-8610-5 the whole document -----	1-6, 12-21
A	WO 2011/157306 AI (ABB RESEARCH LTD [CH]; BERGGREN BERTIL [SE]; WANG JIANPING [SE]; PAN J) 22 December 2011 (2011-12-22) pages 6,7 ----- -/-	1-21

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 29 May 2013	Date of mailing of the international search report 10/06/2013
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Tri fonov, Antony
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/052760

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	wo 2011/157305 AI (ABB RESEARCH LTD [CH] ; BERGGREN BERTI L [SE] ; WANG JIANPING [SE] ; PAN J) 22 December 2011 (2011-12-22) the whol e document -----	1-21

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/EP2013/052760

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
wo 2011157306	AI	22-12-2011	CN 103004049 A EP 2580829 AI US 2013077204 AI WO 2011157306 AI

wo 2011157305	AI	22-12-2011	CN 103004048 A EP 2580828 AI US 2013088802 AI WO 2011157305 AI
