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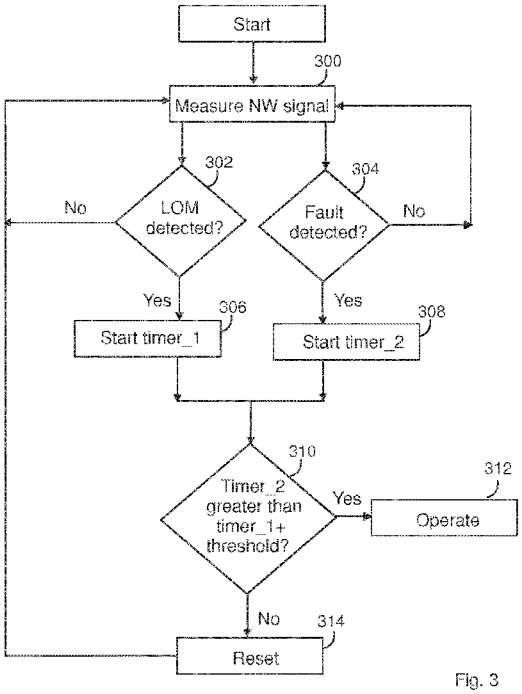


Fig. 3

(57) Abstract: A device for detecting an islanding condition in an electricity distribution network. The device comprises means for concurrently monitoring an islanding condition and a network event condition in the electricity distribution network, means for detecting an islanding condition in the power system network, and means for determining on the validity of detection of the islanding condition based on whether there is an associated network event with the detected islanding condition.

IMPROVEMENT FOR ISLANDING DETECTION RELIABILITY IN ELECTRICITY DISTRIBUTION NETWORK

FIELD

The present invention relates to islanding detection in electricity distribution network.

BACKGROUND

Distributed energy resource (DER) units connected to the distribution networks have potential to reduce the demand for distribution and transmission network capacity, reduce losses and also increase the reliability of electricity supply to the customers. Also interconnection IEDs of distributed generation (DG) should have enabling functionalities to support active management of future distribution networks and support the realization of vision from environmentally friendly, energy efficient and reliable electricity distribution system i.e. Smart Grids. One of functionalities required from a DG interconnection IED is a reliable detection of islanding, also called loss-of-mains (LOM) or anti-islanding protection.

Techniques proposed for islanding detection can be generally divided into two categories: communication based and local detection based methods. The local detection methods include so called active methods, where the measurement points sends some sort of test signal to the network. An example of such a method is disclosed in EP 1764 894. Local detection methods also include passive methods, where the measurement point looks for transient events in the network.

The benefits of communication based LOM protection are lack of non-detection zone (NDZ) near power balance situation and lack of unwanted DG trips, that is, nuisance tripping due to other network events. However, the communication based LOM detection requires high-speed operation. The main challenges of communication based transfer trip LOM schemes are availability and cost of high-speed communication as well as flexibility to network topology changes. However, if communication based methods are not available, or communication fails or is not high-speed enough, a reliable LOM method based on local detection is still required in future, but it has to overcome the major drawbacks of traditional LOM methods.

Active local methods have in some cases been questionable, because they introduce disturbances into the distribution network which may become a serious problem when the number of DG units increases in future.

The main focus in recent years has been on the communication based methods and the active methods, and the study of passive methods has been reducing due to a belief that they could not fulfill the demands in terms of speed, reliability, and avoiding unnecessary trip decisions.

Passive methods are based on monitoring one or more system parameters locally and making the trip decision without directly interacting with the network. Known passive LOM detection methods include monitoring of frequency (*f*), rate-of-change-of-frequency (ROCOF / *df/dt*), vector shift (VS), phase jump or voltage (*U*). The main problems with these known prior methods are failure to detect islanding near power balance and nuisance tripping of DGs.

ROCOF is the most commonly employed passive LOM detection technique. However, the security of ROCOF relays is continually being questioned, as it is sensitive to network disturbances, leading to nuisance tripping.

This method is highlighted by way of a simulation result of Figure 5. The x-axis shows the time in seconds, and the y-axis shows the rate of change of frequency parameter. The axis further shows some network events. At the time moment 0.6-0.9 s, an islanding condition occurs and at 2.3 s, capacitor switching occurs at a HV/MV substation. Three faults are also shown. At 3.0-3.15 s, there is a 1-phase-to-earth fault of another feeder, at 3.9-4.05 s there is a 1-phase-to-earth fault of the same feeder, and at 4.8-4.95 s there is a 3-phase fault in another feeder.

If assumed that the threshold setting would be in 6 Hz/s, ROCOF would cause a tripping in the other four events, but not in the desired one that is in the islanding event.

Generally, in ROCOF-based protection, compromise has to be made between the relay's security and dependability. Reducing the trip threshold can reduce the non-detection zone, that is, more events in the network are detected. This approach, however, could make the relays too sensitive, resulting in more nuisance trips. As Figure 5 shows, however, finding a proper threshold value is practically impossible.

As it is difficult to select a single criterion that would work in most situations, some multi-criteria approaches have been proposed. One multi-

criteria approach has been disclosed in US 2010/0286838, which uses ROCOF and frequency as parameters. The proposed method basically, however, suffers from the same deficiencies as the single ROCOF, that is there is difficult to find correct settings for the threshold values such that the operation would be sensitive enough but would avoid nuisance tripping.

Thus, a reliable, local measurement based island detection algorithm without NDZ and nuisance tripping of DG units is still needed and improvements to the current passive methods are required.

SUMMARY

An object of the present invention is to provide an electricity distribution network device and a method so as to alleviate the above disadvantages. This object is achieved with an invention, which is defined in the independent claims. Some embodiments are disclosed in the dependent claims.

In the present invention, together with an islanding detection it is checked if there are associated network disturbances such as faults or events. The association of the islanding condition and the fault/event condition is considered to exist if the two occur substantially at the same time or within a predetermined time frame. In such a case, the fulfilment of the islanding condition may be a faulty one, and may be caused by the network fault/event.

The network fault refers here to one and two phase earth faults, two and three phase short-circuit faults. Network events include voltage dip situations in superior voltage levels (such as in high-voltage network) in the network, and also coupling operations, which cause short-term changes in voltage. Such coupling operations include coupling of a capacitor at the substation or somewhere else in the network, coupling of a load or transformer to the network, network topology change or re-configuration of feeders, for instance.

In the following, when discussing network disturbances other than islanding/LOM, the terms network event and network fault are both used. In a broad sense, the term network event, however, covers both network events, and network faults.

When detecting the existence of an islanding condition or a network disturbance, different set of criteria are used. That is, the set of parameters which form the basis of detection are at least in some extent mutually

different.

The network of the present invention refers to a medium voltage or a low voltage network.

By utilizating the fault detection information with the fault detection block, the islanding detection reliability and selective operation of loss-of-mains (LOM) protection can be substantially improved. Fault detection can be used for islanding detection together with any passive islanding detection method. This passive islanding detection method can be used for LOM protection alone or as part of so called hybrid method which comprises features from some passive and active methods. Passive islanding detection method can be based, for instance, on measurement of one or more of the following parameters:

- frequency or change in frequency
- rate-of-change-of-frequency (ROCOF / df/dt) or change in df/dt
- vector shift / vector surge / phase jump or change in vector shift / vector surge / phase jump
- voltage or change in voltage including phase-to-earth and phase-to-phase voltage values
- rate-of-change-of-voltage or change in rate-of-change-of-voltage
- active power or change in active power
- reactive power or change in reactive power
- rate-change-of-active-power (dP/dt) or change in dP/dt
- rate-change-of-reactive-power (dQ/dt) or change in dQ/dt
- ratio-of-the-frequency-change-to-the-output-power-change (•f/•P) or change in ratio-of-the-frequency-change-to-the-output-power-change (•f/•P)
- power factor (cos(phi)) or change in power factor
- impedance or change in impedance
- voltage unbalance or change in voltage unbalance
- one specific voltage harmonic or change in one specific voltage harmonic
- one specific current harmonic or change in one specific current harmonic
- more than one voltage harmonics (voltage total harmonic distortion, U_THD) or change in more than one voltage harmonic (U_THD)

- more than one current harmonic (current total harmonic distortion, I_THD)or change in more than one current harmonic (I_THD)
- locally delayed voltage angle signal
- angle calculated from the local value of df/dt
- frequency extrapolation
- accumulated phase angle drift (PAD)
- wavelet transform-based parameters
- rate-of-change of phase
- rate-of-change of the slip

By usage of event detection in connection with these islanding detection parameters, substantial improvement to the islanding detection can be obtained, and disadvantages traditionally associated with the passive islanding methods can be avoided.

In an embodiment, passive islanding methods can be used which do not react to network events, but only to network faults. In this embodiment, only real fault situations need to be monitored.

Such advantages are obtained, when the decision of an islanding condition is based on measurement of change in voltage total harmonic distortion (THD), and change of voltage unbalance.

The voltage THD is measured for a number of harmonic components, which may be 15, for instance. The number of components is not limited to15, but may be 10, 25 or 30, for instance. The THD is determined for each phase component (a, b, c) in the three-phase signal.

The reason in using voltage THD is that variations in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has converter based DGs. In the invention, islanding is detected by monitoring the change of voltage total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed. The monitoring is based on a predetermined threshold value, that is, the change of the THD is used as the decisive criteria. It is required that the change can be seen in all phase components of the signal.

It is especially advantageous to apply change (delta) parameters in the decision making. A voltage THD would have the disadvantage that nuisance tripping could not be avoided due to other network events and disturbances. That is, setting of an appropriate limit value that would provide

satisfactory performance cannot adequately be performed.

Furthermore, it is advantageous to apply a multiple harmonic components instead of one specific harmonic, like for example third harmonic, in determining the tripping condition. In different electricity distribution networks with different amount of overhead lines and cables or DG units, and based on different kind of converters and/or generators by using multiple harmonic components, correct detection can be ensured when compared to the usage of one particular harmonic.

The principle of utilizing voltage THD is that, in normal operation, the distribution network acts as a stiff (low impedance) voltage source, maintaining a low distortion voltage (THD • 0) on the DG unit terminals. Two mechanisms are expected to cause an increase in voltage THD when an island occurs. First, the impedance at the DG unit terminals changes because the low impedance distribution network is disconnected and only the local load remains. As a result, current harmonics in the DG unit output current will cause increased levels of voltage harmonics in the terminal voltage. Second, non-linear loads within the island, particularly distribution step-down transformers, will be excited by the output current of the DG unit. The voltage response of the non-linear loads to the current excitation can be highly distorted.

Voltage THD is quite a sensitive criterion, and therefore many network disturbances will be noticed. Nuisance trippings can be avoided by setting threshold limits that are sufficiently long such that fault indications which are not caused by a LOM condition will be able to disappear.

The use of change of voltage THD has the further advantage in that it does not have a NDZ when the local load matches the DG output power, that is, in a load balance situation.

Voltage THD is a superior criterion in LOM detection over current THD, because in certain cases with converter based DG units with good filters, non-detection zone for current THD may exist. The current THD also depends from the current magnitude, and when for example production of photovoltaic panels or wind turbines rapidly changes, also the current THD changes. So setting a detection limit for current THD based LOM algorithm might be impossible to ensure satisfactory selective LOM detection.

Another criterion in the present invention to detect LOM is the voltage unbalance. As the distribution networks generally include single-phase

loads, it is highly possible that after islanding, voltage unbalance will occur due to the change in network condition i.e. transition from stiff to weak grid and.

The voltage unbalance criterion is advantageous because it provides quickly an indication of the islanding situation, but is immune to many of the network disturbances. The use of voltage unbalance also as a change parameter instead of a voltage unbalance threshold value is advantageous, as the setting of a fixed threshold is difficult in varying network structures.

The two criteria, voltage THD of all phase components and voltage unbalance complement each other, because they both rely on natural response of the system when changing from strong grid to weak grid. The usage of these parameters together makes the LOM detection much faster and more reliable by confirming the LOM detection of another parameter and by improving the selectivity for example in case of connection of capacitor bank to HV/MV substation or in case of unsymmetrical voltage dips or unsymmetrical faults on other MV feeders. Therefore the non-detection zone in power balance situation will be minimized.

The combined use of change of voltage THD and change of voltage unbalance has remained unnoticed to the skilled person because lack of knowledge about detailed network behavior and lack of enough realistic simulation models as well as lack of field measurements. In many earlier suggestions made for LOM detection more simplified models or laboratory setups with many simplifications related to type of network, loads and DG units have been made which does not respond enough with the reality. It has also been a common to try to find only one single parameter to be used for LOM detection. However, this task has proven to be very difficult in terms of minimizing non-detection zone and amount of nuisance tripping. Also the trend in recent years has been to investigate more communication and active or hybrid LOM methods, whereby the focus has moved away from passive methods.

The present invention where the event detection of a network event is used together with the passive/hybrid islanding detection, the performance of the islanding detection can be significantly improved, because several indicated loss of mains situations can be avoided. Special advantages are obtained with traditional passive islanding methods, such as ROCOF, for instance, which has proved to be difficult to use due to problems in tripping threshold settings. By way of the invention, the islanding indications

given by the islanding method can be verified.

DRAWINGS

In the following, the invention will be described in greater detail by means of some embodiments with reference to the accompanying drawings, in which

Figure 1 shows an embodiment of an electricity distribution network;

Figure 2 shows an embodiment of a method;

Figure 3 shows another embodiment of a method;

Figure 4 shows an embodiment of an electricity distribution network device;

Figure 5 shows a simulation result when ROCOF is used; and

Figure 6 shows a simulation result using voltage unbalance;

Figure 7A shows a simulation result of a first phase of voltage total harmonic distortion;

Figure 7B shows a simulation result of a second phase of voltage total harmonic distortion; and

Figure 7C shows a simulation result of a third phase of voltage total harmonic distortion.

DETAILED DESCRIPTION

Figure 1 shows, on a high level, one embodiment of a network topology where the invention may be applied. The simulation results discussed in subsequent figures are based on the topology of Figure 1.

In Figure 1, the feeder network 100 illustrates a high voltage/medium voltage (HV/MV) substation having, by way of an example, three outgoing medium voltage lines 120, 122, 124 each provided with a corresponding circuit breaker. The network elements along the second line 122 are discussed more in detail in the following.

Figure 1 shows three distributed generators DG1, DG2, DG3 connected to the MV network. The DG unit i.e. the generator may be a directly connected synchronous generator (DG1) 102, directly connected induction generator (DG2) 104 or power converter interfaced DG unit (DG3) 106.

The network includes a LOM detection unit 108 which detects various events in the network, which are also shown in the simulation figures. One such even is the opening of the circuit breaker of the second MV feeder

122, which results into detection of loss of mains condition in the LOM unit. Additional events are 1-, 2- or 3-phase-to-earth faults in the second or in neighboring feeder, that is the first 120 or third feeder 124. Additional simulated network events include a sudden increase of load at the beginning of the second feeder, sudden load increase near the feeder line from the DG's, capacitor switching at the HV/MV substation, disconnection of parallel transformer at HV/MV substation and sudden voltage dip in the HV network.

The load in the network is depicted by the block 110.

Figure 2 shows one embodiment of the method. The method can be implemented in a power network including one or more distributed generators. Specifically, the method may be implemented in a protection relay or some other protective network element or inside a DG unit power converter.

In 200, a network signal is measured.

In 202, a change in voltage total harmonic distortion is determined from the measured signal. Preferably the change in voltage total harmonic distortion is determined for each phase (a, b, c) of the signal. There may a predetermined number of harmonic components that are taken into account. In this example, 15 harmonic components for each phase component are used (U_THD15_a, U_THD15_b, U_THD15_c) in the calculations but some other number of harmonics can be selected, such as 10, 25 or 30.

Determination of relative change of ΔU_THD for all phase-to-ground voltages (U_a, U_b, U_c) may be calculated as follows. The task time may be 2,5 ms and a moving average over 10 ms may be used.

The comparison of harmonic contents may be performed to a 30 ms preceding measurement value, for instance. On a time moment "0" the comparison is done to values at time moment "-30 ms", that is, U_THD15_a_t_0, U_THD15_b_t_0, U_THD15_c_t_0 are compared to 30 ms earlier measurements U_THD15_a_t_{-30}, U_THD15_b_t_{-30}, U_THD15_c_t_{-30}. This comparison is performed every 10 ms to calculate relative changes • U_THD15a, • U_THD15b, • U_THD15c.

In 206, the change values are compared to respective threshold values. The threshold setting may be a percentage, for instance. That is, the threshold setting may be 2 %, whereby if the change between the values measured at 30 ms intervals is equal or more than 2 %, a tripping indication based on the current criterion is given.

The threshold values for different phase components may be the same. When all the comparisons of the phase components exceed the threshold value, the method proceeds to step 210 if the voltage unbalance calculation in step 204 also exceeds the threshold value therein.

In step 204, the voltage unbalance change parameter is determined. Thus, the comparison of a current value is done to an earlier value, such as a value measured 30 ms earlier, and if the change rate exceeds a threshold value, a trigger is given. The comparison may be a percentage comparison or absolute values of two measurement moments may be compared to each other. The voltage unbalance determination in 204 may be carried out simultaneously with the harmonic calculation 202. Alternatively the calculations may be dependent on each other. In such a case, only when one of the indicators exceeds the set threshold, the other parameter is calculated.

When both the harmonic comparison of 206 and the voltage unbalance comparison of 208 indicate exceeding of their threshold values, the method proceeds to step 210, where a timer is started. The purpose of the timer is to ensure that the undesired conditions in the network continue a sufficient time period. The set time period may be 80 ms, for instance. This is a sufficient time period to ensure that no faulty indications are given by the parameters. Both of the parameters may give short peaks in various network disturbances but the peaks can be filtered out with a sufficient timer. Even though the timer value suggested here is about 80 ms, the embodiments are not restricted thereto. The timer value may be selected from a range of 40 to 120 ms to provide the desired advantages.

In Figure 2, if the timer expires and both of the parameters have been over their respective threshold values for the whole time period, the method proceeds to 214 where it is confirmed that LOM has occurred. If one or both of the parameters goes below its threshold value during the timer period, the method may be reset and started anew.

Even though Figure 2 discloses use of change of THD and change of voltage unbalance as the islanding detection parameters, islanding detection can be carried out by using one or more other passive islanding detection criteria.

The loss of mains indication may result into different actions being taken. In an embodiment, the distributed generator is shut off from the feeder

network. In another embodiment, the distributed generator is permitted to continue power feeding to the main network. These different actions are discussed in Figure 3.

Figure 3 shows an embodiment of a method where two separate functions are carried out in a protective network element, such as protective relay. The network element incorporates separate functionality for monitoring a loss of mains condition, and a function for monitoring a fault detection condition to further minimize the number of nuisance tripping of DG unit LOM detection due to faults.

In 300, a electricity distribution network signal is measured.

In 302, a loss of mains condition is measured. The detection of loss of mains condition can be carried out using the method of Figure 2, for instance.

In 304, there is provided fault and event detection functionality. The fault detection can be based on phase-to-earth voltages or on phase-to-phase under-voltage detection. Other possibilities for fault detection include signal/information from other protection functions, such as residual/zero voltage, • U_0 or U_0, different earth-fault and over-current functions or different voltage functions, such as under-voltage.

In the method, it is evaluated if a detected islanding condition is associated with and caused a network fault conditions, whereby the detection of the islanding condition would be a faulty detection.

Some network fault situation may cause the islanding detection parameters to fulfill their triggering conditions, and in this method these cases are preferably filtered out such as to further improve the performance of the islanding detection functionality.

In an embodiment, the association between the two events, detection of islanding condition and the network fault condition, is determined by evaluating if the two have occurred timely close to each other.

In an embodiment, each function has a respective timer. If loss of mains is detected, timer_1 is started as indicated by step 306. If another network fault is detected, timer_2 is started as indicated by step 308.

In 310 it is checked which one of the timers started first. It is required that the timer_2 is greater than timer_1 more than a predetermined threshold value, such as 50 ms, for instance. The purpose of this step is to find out if the network fault/event is related to the loss of mains detection or

not. If the fault had occurred, for example 80 ms (more than the threshold 50 ms) before the loss of mains detection, this is an indication that there has been an islanding after fault. This means that the fault has occurred in the same feeder which has been islanded by an operation of a feeder circuit-breaker. If this fault has been detected before islanding, this means that the island is faulty. In this situation, the method proceeds to step 312 to cause an immediate operate/triggering, that is disconnection of the island from the rest of the network.

If, on the other hand, step 310 indicates that the fault had occurred, for example, before the threshold 50 ms, the LOM detection, then the function draws a conclusion that the fault caused false LOM detection and to avoid nuisance tripping due to false LOM detection the method goes to step 314, where the functionality is reset and the evaluation of loss of mains condition and fault condition is restarted.

In addition to the use of Figure 3 there are also other use cases. In one such a case, if the loss of mains functionality indicates that there is a loss of mains condition, but there is no fault according to the fault detection functionality, it may be concluded that the question is of a healthy island. There may be separate functionality to determine what to do in such a situation. If not even a healthy island can be allowed in the network, the island is disconnected from the rest of the network. Otherwise, the healthy island may be allowed to continue feeding power to the network.

When loss of mains has been detected, a function may be provided to determine when the loss of mains condition has been removed. In an embodiment, the removal of loss of mains condition utilizes the similar parameters as in detection of loss of mains substantially in an inverse way. It may be monitored if the voltage unbalance parameter and the voltage total harmonic distortion parameter decline rapidly, and this declining continues a predetermined time, it is concluded that the loss of mains condition has removed.

Figure 4 shows one embodiment of a network device 400. The units 402 to 412 relate to detection of islanding or loss of mains condition, units 420 to 426 to fault and event detection condition other than loss of mains, units 430 to 432 to functionality of decision making based on detections of the loss of mains and event detection, and units 440 and 442 depict

general parts of the device. The device may be a protective relay or some other protective device of an electricity distribution network.

The device inputs a network signal via the input/output unit 442. The unit 402 measures, from an input signal, change of voltage total harmonic distortion of 15 harmonic components of the first phase component (a) in the input signal and compares the measuring result to a predetermined triggering condition. The triggering condition may include a threshold setting value, that is if the voltage THD change exceeds a predetermined value, then a triggering condition is deemed to be fulfilled.

Units 404 and 406 perform the same functionality for the other two phase components (b) and (c). Unit 408 measures a voltage unbalance change parameter, which is a change value compared to one or more previous measurements. As the figure shows, there is an AND-condition between these blocks, that is, each of the blocks 402 to 408 is to indicate loss of mains, otherwise loss of mains detection indication is not given.

If all the blocks 402 to 408 indicate detection of loss of mains, a timer 412 is started. LOM coordination unit 410 then observes the expiry of the timer and that the various measurement parameters 402 to 408 stay above their respective thresholds. Finally, if this is the case, a loss of mains indication is given. The loss of mains indication may be directed to a loss of mains verification unit 430, or the indication may be provided for the output unit 442 to disconnect the DG unit from the main network.

It is noted that the embodiment may also function without the timer such that immediately when the measured parameters exceed their threshold limits, a loss of mains indication is given. It is also possible that different parameters have different timers. For instance, total harmonic distortion, voltage unbalance, frequency change and vector shift may each have own timers.

In addition to islanding condition/loss of mains, also other faults may occur in an electricity distribution network. Such faults are monitored by units 420 to 426. In the embodiment of Figure 4, a fault indication is given if one of blocks 420 (earth fault indication) or 422 (voltage drop of one of the phases) gives a fault indication. The fault detection coordination unit 424 starts a timer 426 when at least one of the blocks 420 or 422 gives such an indication. The fault detection coordination unit 426 monitors the expiry of the timer and whether the parameters measured in 420, 422 stay over their re-

spective threshold levels. As an output the block 424 either gives an indication of a network fault or does not indicate a fault.

There is also provided a set of blocks 430 to 434, which take decisions based on the eventual loss of mains and/or fault detection conditions. The loss of mains verification unit 430 receives inputs from the loss of mains and fault detection coordination units 410, 424 and monitors whether fault indications from the two are substantially simultaneous. The purpose is to filter out the effects of other network faults from the loss of mains detection.

In an embodiment, the unit 430 compares the timers run in blocks 412 and 426 and gives outputs based on the comparison. If, for instance, a network fault was detected well before the islanding condition, it may be concluded that the network island is a faulty island and needs to be disconnected immediately.

Otherwise, if it noticed that the timer_2 is less than 50 ms greater than timer_1, it may be concluded that the loss of mains indication given by the blocks 402 to 408 may be incorrect. In such a case the loss of mains indication, that is exceeding of threshold values (THD, VU) can take place for example due to a network fault, such as a fault on a neighboring feeder.

The unit 430 may also monitor that a network fault has removed more than a predetermined time period, eg. 50 ms, before a LOM condition is fulfilled. This is due to the case that when a neighboring feeder is disconnected due to a 3-phase fault, for instance, this may cause a temporary exceeding of LOM criteria. In this way it may be avoided that an erroneous “healthy island” indication is given, for instance, due to fault clearance on other feeders, that is when there is no network fault but there exists a LOM condition for a short moment. Otherwise, fault clearance on other feeders could possibly lead to nuisance tripping especially if very fast LOM detection is required or preferred, as for example a LOM detection in less than 100 ms.

The implementation of the fault detection functionality in connection with the LOM functionality provides an important advantage in that the performance of the LOM functionality can be further improved and to further ensure selective operation and to avoid nuisance trippings. That is, some LOM indications which actually do not represent a LOM condition can be avoided.

In Figure 4, the unit 440 depicts a general controller unit of the device. The controller may be implemented on a processor of the device, for instance.

In the following Figures 5 to 7, some simulation results are discussed. The time scale shown on the x-axis and the events in the figures are the same. The simulation network is on a coarse level the one presented in Figure 1.

The simulation sequence in Figures 5 to 7 was following:

- Islanding at (0.6 - 0.9 s) in almost perfect power balance (• P and • Q in at the beginning of MV feeder are zero i.e. power flow from the utility grid to the MV feeder is almost zero)
- Events or disturbaces which should not lead to tripping decision of LOM detection (i.e. nuisance tripping):

i. Sudden load increase at the beginning of the feeder, passive balanced load (1.4 s)

ii. Sudden load increase near the PCC of the MV feeder DG unit, passive balanced load (1.6 s)

iii. Operation of on-load-tap-changer at HV/MV substation, (1.8 s)

iv. Capacitor switching at HV/MV substation, 0.4 MVAr (2.3 s)

v. Disconnection of parallel transformer at HV/MV substation (2.6 s)

vi. 1-phase-to-earth (A-G) fault 150 ms at the end of adjacent MV feeder (fault resistance R_f = 750 ohm) (3.0 - 3.15 s)

vii. 1-phase-to-earth (B-G) fault 150 ms at the beginning of adjacent MV feeder (fault resistance R_f = 100 ohm) (3.45 - 3.6 s)

viii. 1-phase-to-earth (A-G) fault 150 ms in the middle of the same MV feeder (fault resistance R_f = 1000 ohm) (3.9 - 4.05 s)

ix. 2-phase (A-B) fault 150 ms in the middle of adjacent MV feeder (fault resistance R_f = 5 ohm) (4.35 - 4.5 s)

x. 3-phase (A-B-C) fault 150 ms at the beginning of adjacent MV feeder (fault resistance R_f = 1 ohm) (4.8 - 4.95 s)

xi. 3-phase 30 % voltage dip in HV network (5.3 - 5.45 s)

Figure 5 illustrates the results of a detection arrangement, where the measurement is based on frequency using rate-of-change of frequency (ROCOF).

When detecting the islanding condition, using ROCOF, in almost a perfect power balance situation occurring at 0.6 to 0.9 seconds, it is noticed that the method produces a first peak, where after the level drops considerably. The time period 0.7 to 0.9 is problematic, because the method should still consider this level of signal as fulfilling the islanding condition. Therefore, the threshold level should be set low enough.

Other indicated network events also produce high peaks, such as faults and fault clearances on adjacent feeders. Therefore nuisance trippings are very probable especially when high-speed LOM detection is required. As Figure 5 shows, finding a proper threshold value for LOM detection based on ROCOF is practically impossible.

However, the performance of ROCOF-based islanding detection can be significantly improved when network event monitoring is associated with the detection. By providing network event monitoring, the false islanding indications can be avoided. It can be monitored if the event monitoring detects a network event, which is timely close enough to the islanding detection. If there is such an event, the islanding indication can be concluded to possibly be a faulty indication, which is to be verified. The measuring of islanding condition can thereby be restarted. If the islanding condition repeats, and the fault condition has removed, the islanding detection is accepted.

In Figure 6 voltage unbalance (VU) or change in VU values during the simulation sequence are presented. From Figure 6 it can be seen that voltage unbalance alone is not a fully sufficient criterion for island detection, because for example 2-phase faults at adjacent feeders would lead to unwanted tripping of DG units.

In Figures 7A to 7C, the voltage THD (%) values including harmonics up to 15th harmonic from phases A, B and C during the simulation sequence are shown. It can be seen that if change in multiple harmonics from all phase voltages A, B and C are use alone for high-speed islanding detection, there is a risk that for example capacitor switching at HV/MV substation (2.3 s) or a clearance of faults on adjacent feeders could cause nuisance tripping. If only multiple harmonics from one phase voltage would be used for LOM detection, the number of nuisance trippings would be even further increased. Therefore it is preferred to utilize multiple harmonics from all phase voltages as part of the LOM detection.

Due to above mentioned reasons, the usage of a change parameter in voltage THD values from all phases together with a change parameter of voltage unbalance for LOM detection tremendously improves the selectivity and reduces nuisance trippings of LOM detection.

By utilization of fault detection information, the selective operation of LOM algorithm can be even further ensured and improved. In case of a 150 ms 2-phase (A-B) fault in the middle of an adjacent MV feeder (fault resistance R_f = 5 ohm) (4.35 - 4.5 s), LOM detection can be prevented by applying fault detection based on one of a phase-to-earth or a phase-to-phase voltage under-voltage (e.g. 0.95 pu) criterion, as illustrated by Figs. 6 and 7. Other possibilities which could be used for preventing a LOM detection, are difference between voltage THD in a remaining healthy phase (C) when compared to two faulty phases B and C (see Figs. 7A to 7C) or LOM detection prevention when voltage unbalance upper limit, e.g. 10 %, is exceeded.

On the other hand, to avoid a false “Healthy island detection” for example after clearance of a 3-phase fault on the other feeder (4.8 - 4.95 s), the fault detection status could be “no fault” for e.g. 50 ms before Start time 1 of timer_1 for LOM detection when high-speed detection of LOM is required. In accordance with an exemplary embodiment, such as Figure 4, the protection relay may comprise a processor, which can be a general-purpose processor configured to execute a computer program tangibly recorded on a non-transitory computer-readable recording medium, for example, a ROM, hard disk drive, optical memory or flash memory. In this case, the general-purpose processor can be configured to carry out the operative functions described herein by executing the computer program recorded on the non-transitory computer-readable recording medium. In accordance with an exemplary embodiment, the processor can be an application specific processor that is specifically configured to carry out the operative functions described herein. The non-transitory computer-readable recording medium can be a memory resident in the protective relay and/or communicatively connected to the protective relay.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

CLAIMS

1. A device for detecting an islanding condition in an electricity distribution network, **characterized** in that the device comprises:

means for concurrently monitoring an islanding condition and a network event condition in the electricity distribution network;

means for detecting an islanding condition in the power system network; and

means for determining on the validity of detection of the islanding condition based on whether there is an associated network event with the detected islanding condition.

2. A device according to claim 1, **characterized** in that the device comprises means for giving an islanding indication if there is no associated network event.

3. A device according to any preceding claim, **characterized** in that the device comprises means for accepting the detection of the islanding condition as a valid detection if there is no associated network event.

4. A device according to any preceding claim, **characterized** in that the device comprises means for restarting the detection of islanding condition if there is an associated network event.

5. A device according to any preceding claim, **characterized** in that the device comprises means for concluding that the islanding detection is associated with a network event if the two conditions are detected within a predetermined time frame.

6. A device according to any preceding claim, **characterized** in that the device comprises means for monitoring disappearance of the detected islanding condition which uses substantially inverse criteria than the detection of the islanding condition.

7. A device according to any preceding claim, **characterized** in that the device comprises means for monitoring the islanding condi-

tion based on a voltage unbalance parameter and one or more voltage total harmonic threshold parameters.

8. A method of detecting an islanding condition in an electricity distribution network, **characterized** by:

monitoring concurrently an islanding condition and a network event condition in the electricity distribution network;

detecting an islanding condition in the power system network; and

determining if an indication of an islanding condition is given based on whether there is an associated network event with the detected islanding condition.

9. A method according to claim 8, **characterized** by giving an islanding indication if there is no associated network event.

10. A method according to any preceding claim 8 or 9, **characterized** by re-evaluating the detection of islanding condition if there is an associated network event.

11. A method according to any preceding claim 8 to 10, **characterized** by restarting the detection of islanding condition if there is an associated network event.

12. A method according to any preceding claim 8 to 11, **characterized** by concluding that the islanding detection is associated with a network event if the two conditions are detected within a predetermined time frame.

13. A method according to any preceding claim, **characterized** by monitoring disappearance of the detected islanding condition which uses substantially inverse criteria than the detection of the islanding condition.

14. A method according to any preceding claim, **characterized** by monitoring the islanding condition based on a voltage unbalance parameter and one or more voltage total harmonic threshold parameters.

15. A computer program product configured to perform the method according to any preceding method claim 8 to 14 when run on a computer.

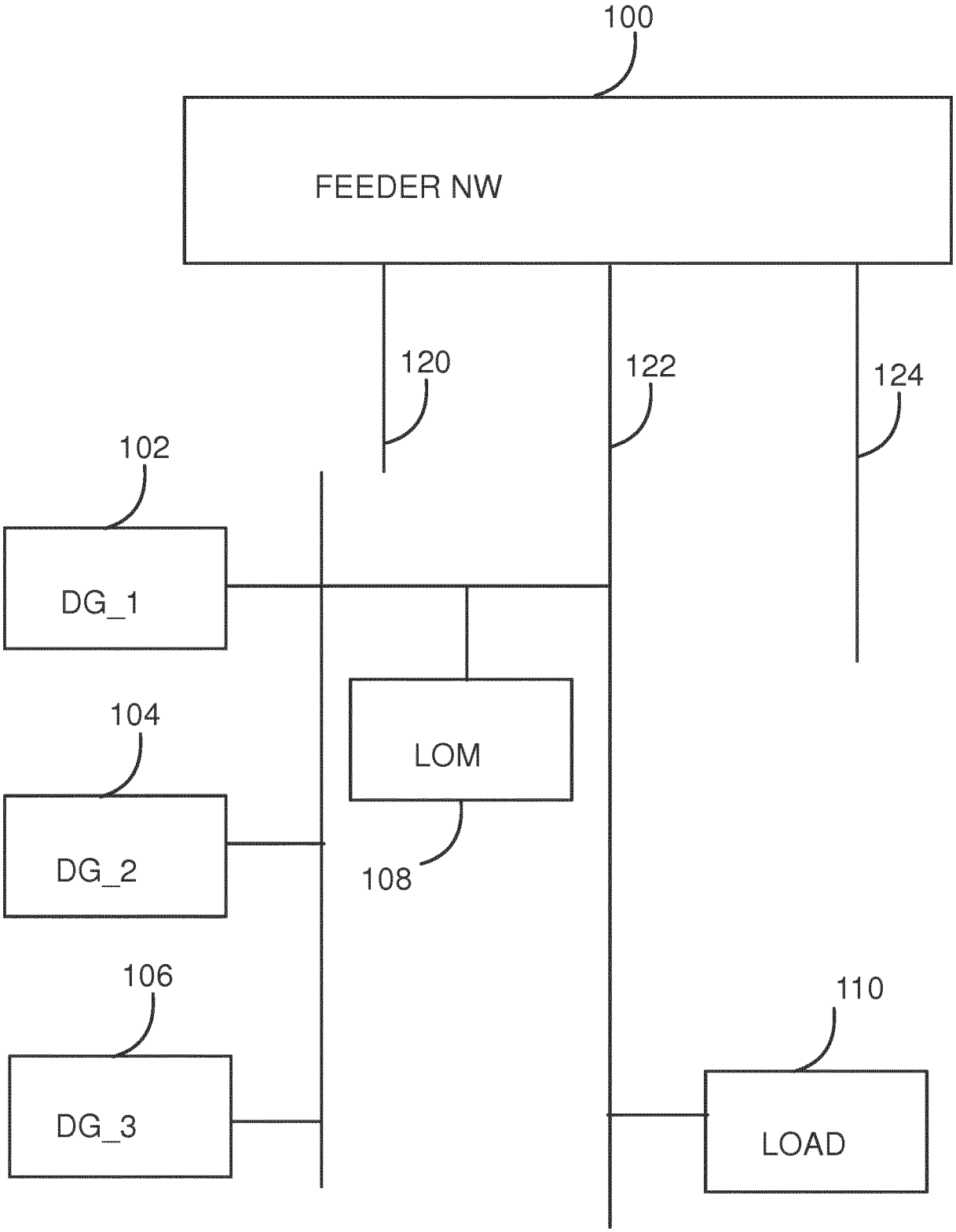

100
FEEDER NW
120
122
124
102
DG_1
LOM
104
DG_2
108
106
110
DG_3
LOAD

Fig. 1

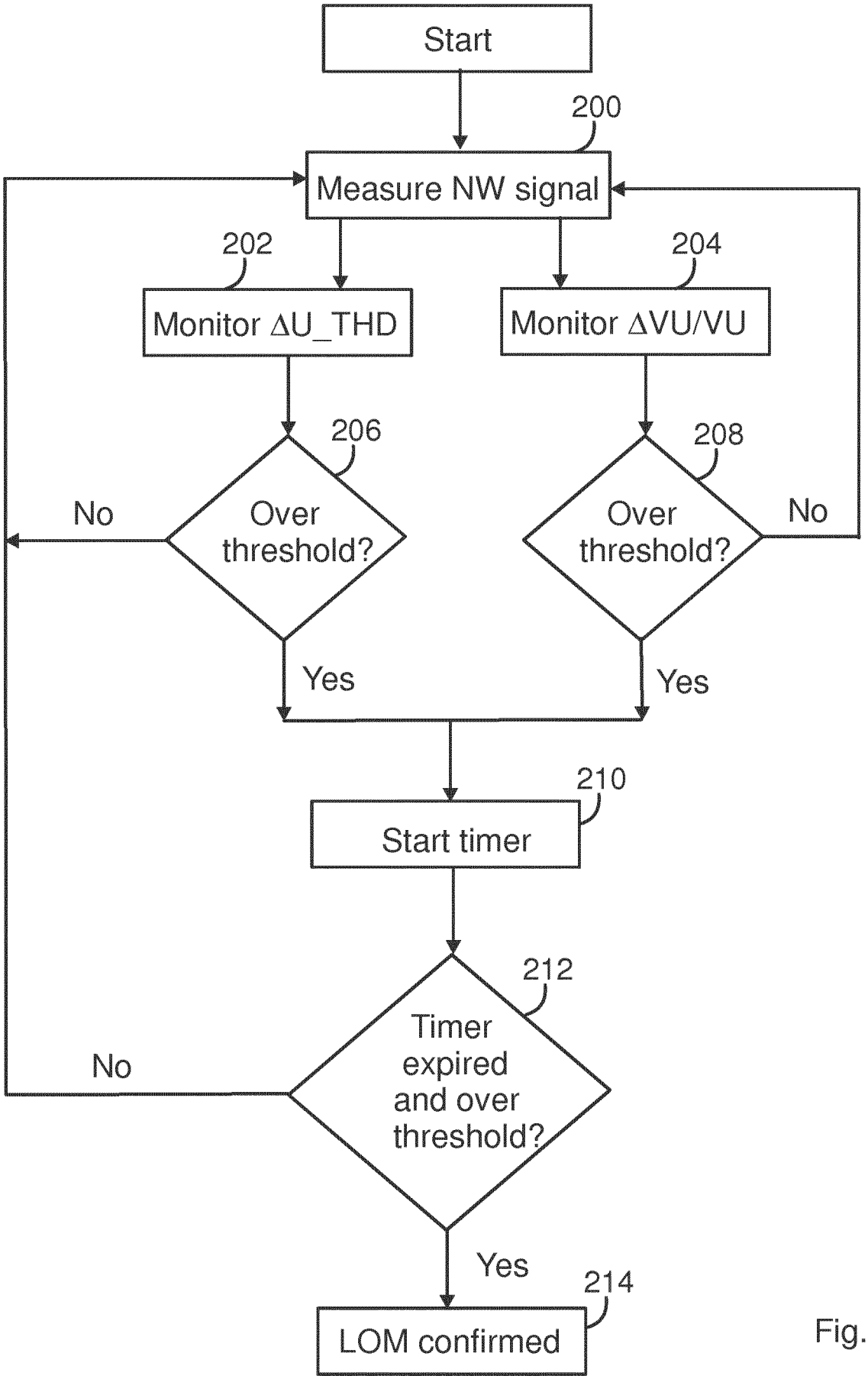

Start
200
Measure NW signal
202
Monitor ΔU_THD
204
Monitor ΔVU/VU
206
Over threshold?
No
208
Over threshold?
No
Yes
Yes
210
Start timer
212
Timer expired and over threshold?
No
Yes
214
LOM confirmed

Fig. 2

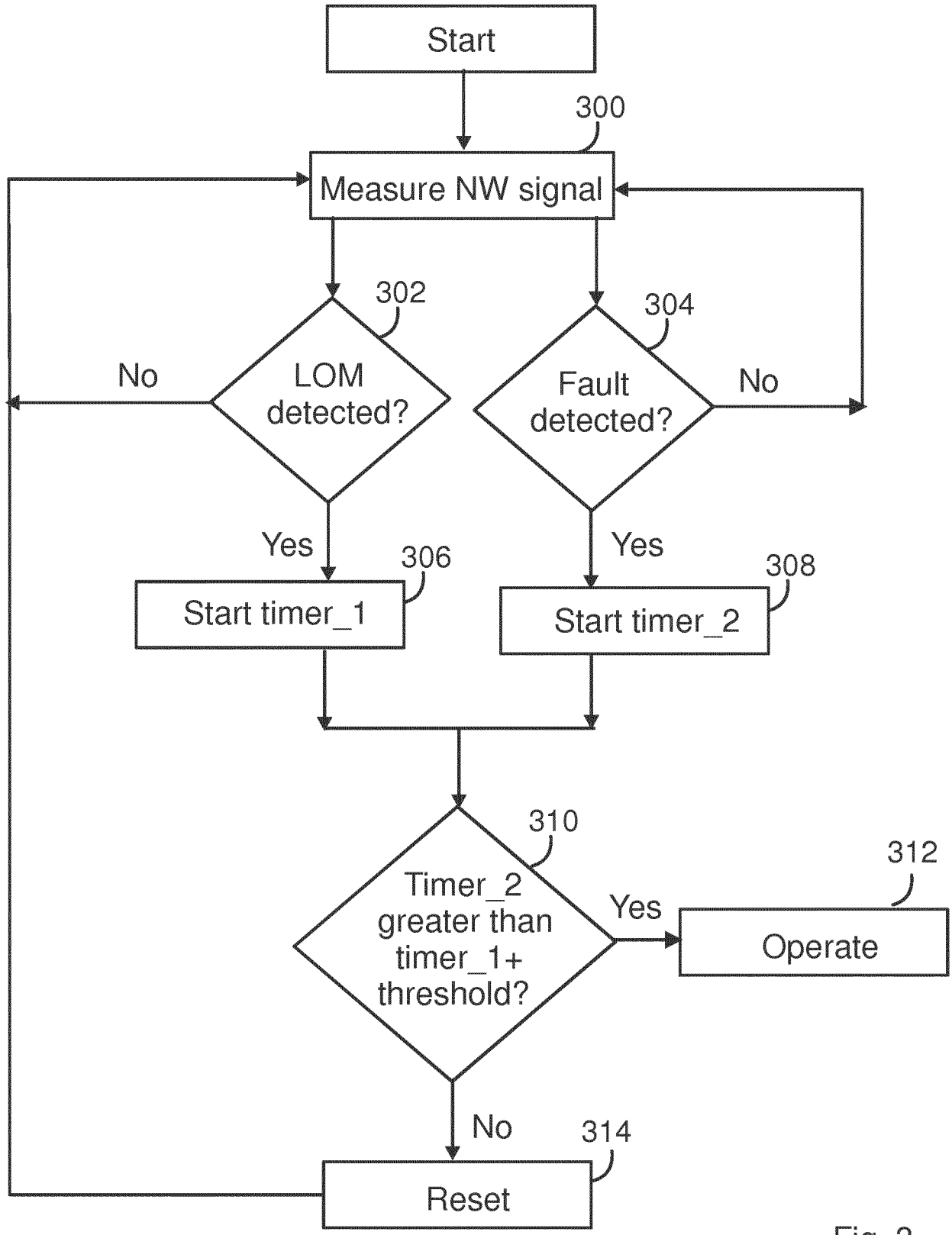

Start
300
Measure NW signal
302
LOM detected?
No
Yes
304
Fault detected?
No
Yes
306
Start timer_1
308
Start timer_2
310
Timer_2 greater than timer_1+ threshold?
Yes
312
Operate
No
314
Reset

Fig. 3

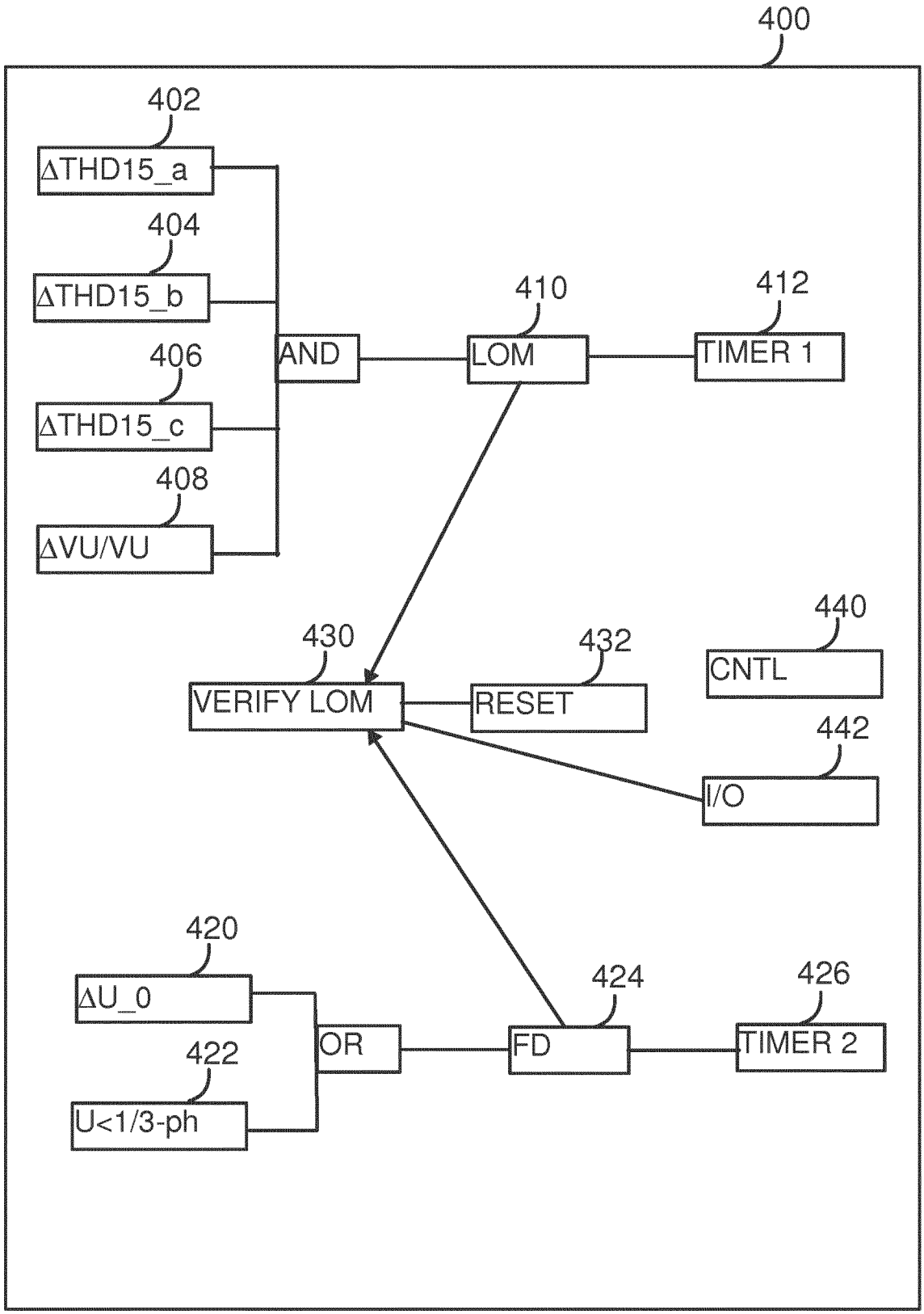

400
402
ΔTHD15_a
404
ΔTHD15_b
406
ΔTHD15_c
408
ΔVU/VU
AND
410
LOM
412
TIMER 1
430
VERIFY LOM
432
RESET
440
CNTL
442
I/O
420
ΔU_0
422
U<1/3-ph
OR
424
FD
426
TIMER 2

Fig. 4

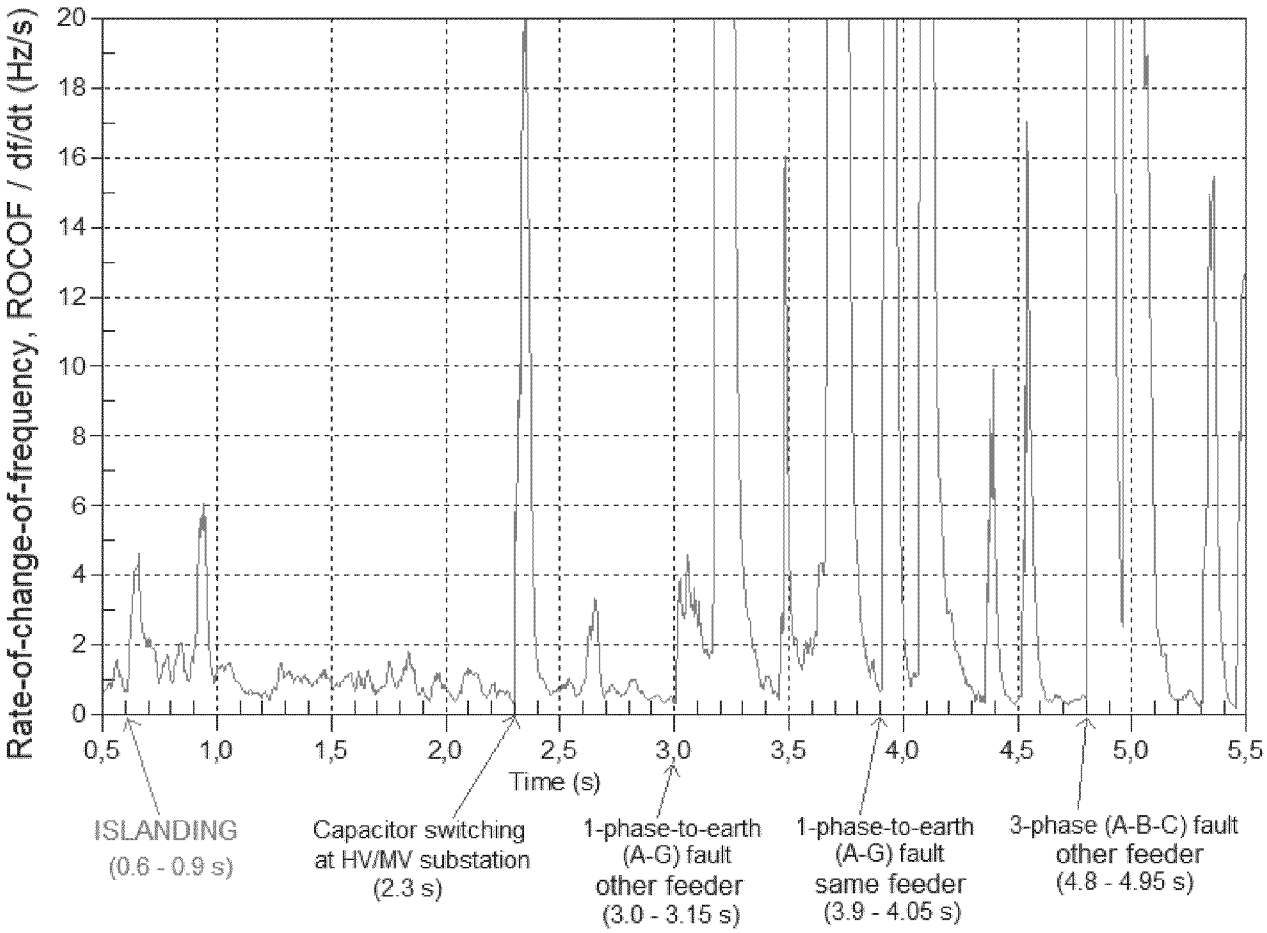

Rate-of-change-of-frequency, ROCOF / df/dt (Hz/s)
20
18
16
14
12
10
8
6
4
2
0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
Time (s)
ISLANDING
(0.6 - 0.9 s)
Capacitor switching
at HV/MV substation
(2.3 s)
1-phase-to-earth
(A-G) fault
other feeder
(3.0 - 3.15 s)
1-phase-to-earth
(A-G) fault
same feeder
(3.9 - 4.05 s)
3-phase (A-B-C) fault
other feeder
(4.8 - 4.95 s)

Fig. 5

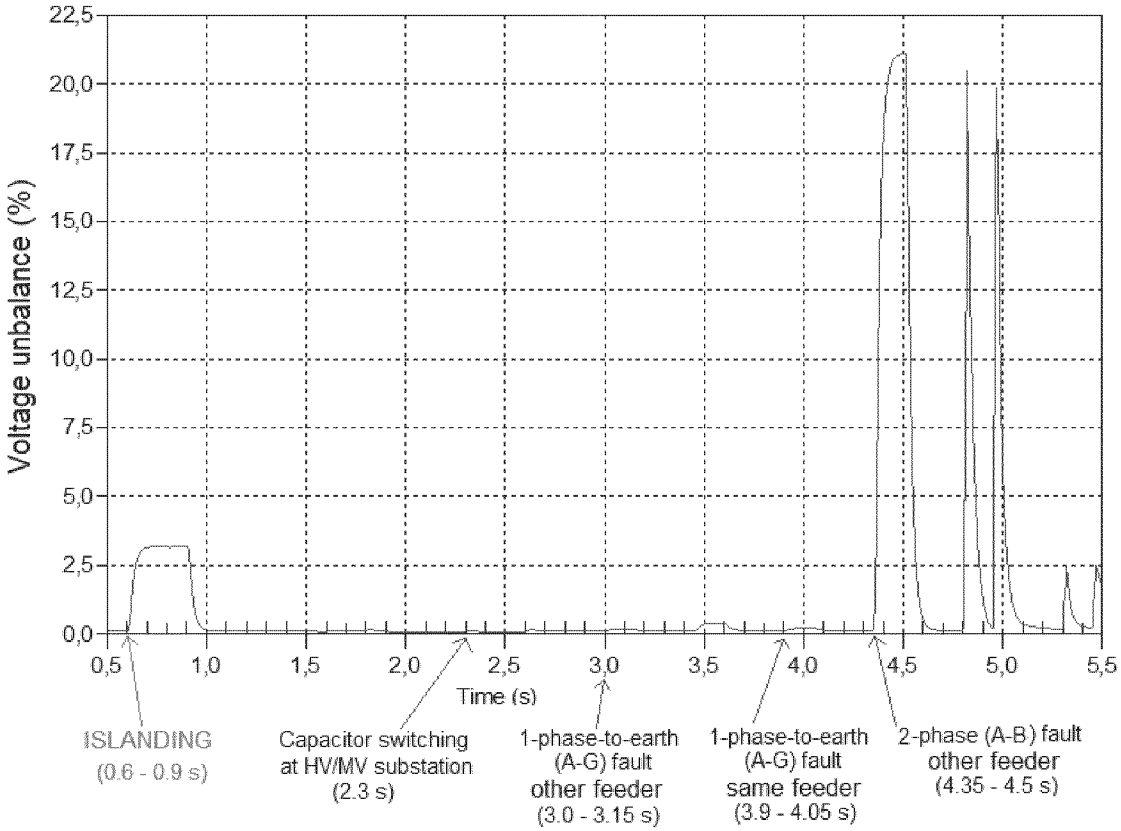

Voltage unbalance (%)
22,5
20,0
17,5
15,0
12,5
10,0
7,5
5,0
2,5
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
Time (s)
ISLANDING
(0.6 - 0.9 s)
Capacitor switching
at HV/MV substation
(2.3 s)
1-phase-to-earth
(A-G) fault
other feeder
(3.0 - 3.15 s)
1-phase-to-earth
(A-G) fault
same feeder
(3.9 - 4.05 s)
2-phase (A-B) fault
other feeder
(4.35 - 4.5 s)

Fig. 6

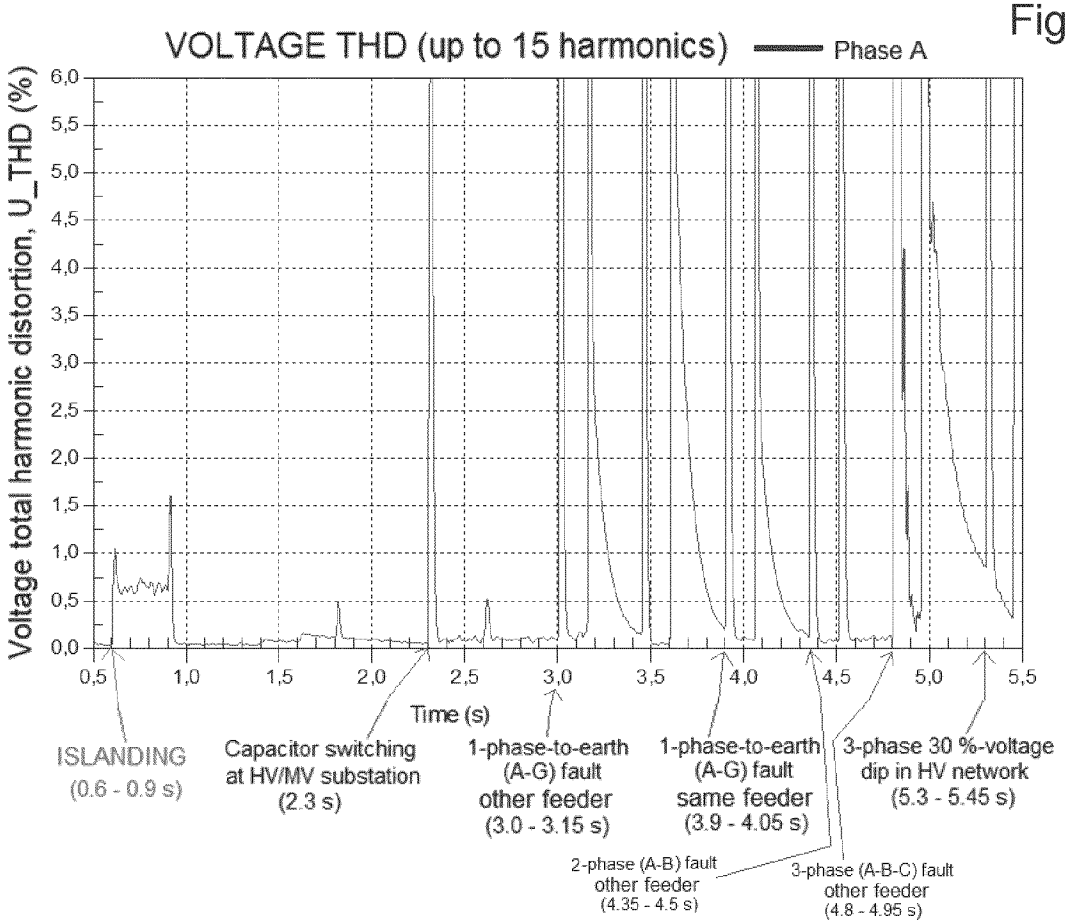

VOLTAGE THD (up to 15 harmonics)
Phase A
Voltage total harmonic distortion, U_THD (%)
6,0
5,5
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
Time (s)
ISLANDING
(0.6 - 0.9 s)
Capacitor switching
at HV/MV substation
(2.3 s)
1-phase-to-earth
(A-G) fault
other feeder
(3.0 - 3.15 s)
1-phase-to-earth
(A-G) fault
same feeder
(3.9 - 4.05 s)
3-phase 30 %-voltage
dip in HV network
(5.3 - 5.45 s)
2-phase (A-B) fault
other feeder
(4.35 - 4.5 s)
3-phase (A-B-C) fault
other feeder
(4.8 - 4.95 s)

Fig. 7A

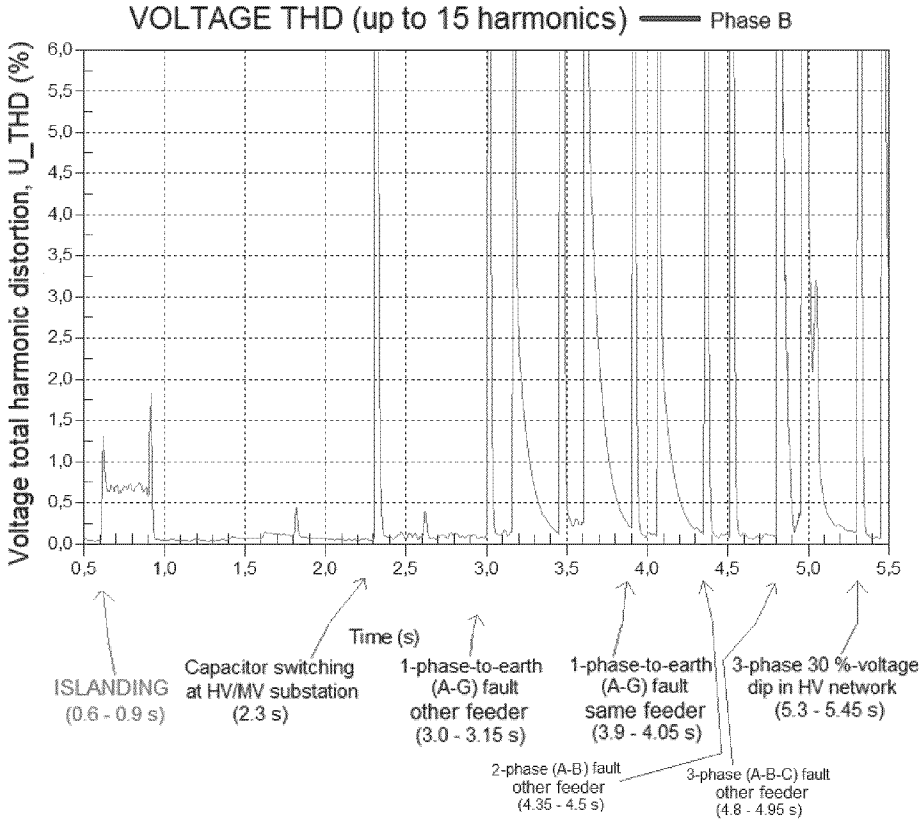

VOLTAGE THD (up to 15 harmonics)
Phase B
Voltage total harmonic distortion, U_THD (%)
6,0
5,5
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
Time (s)
ISLANDING
(0.6 - 0.9 s)
Capacitor switching
at HV/MV substation
(2.3 s)
1-phase-to-earth
(A-G) fault
other feeder
(3.0 - 3.15 s)
1-phase-to-earth
(A-G) fault
same feeder
(3.9 - 4.05 s)
3-phase 30 %-voltage
dip in HV network
(5.3 - 5.45 s)
2-phase (A-B) fault
other feeder
(4.35 - 4.5 s)
3-phase (A-B-C) fault
other feeder
(4.8 - 4.95 s)

Fig. 7B

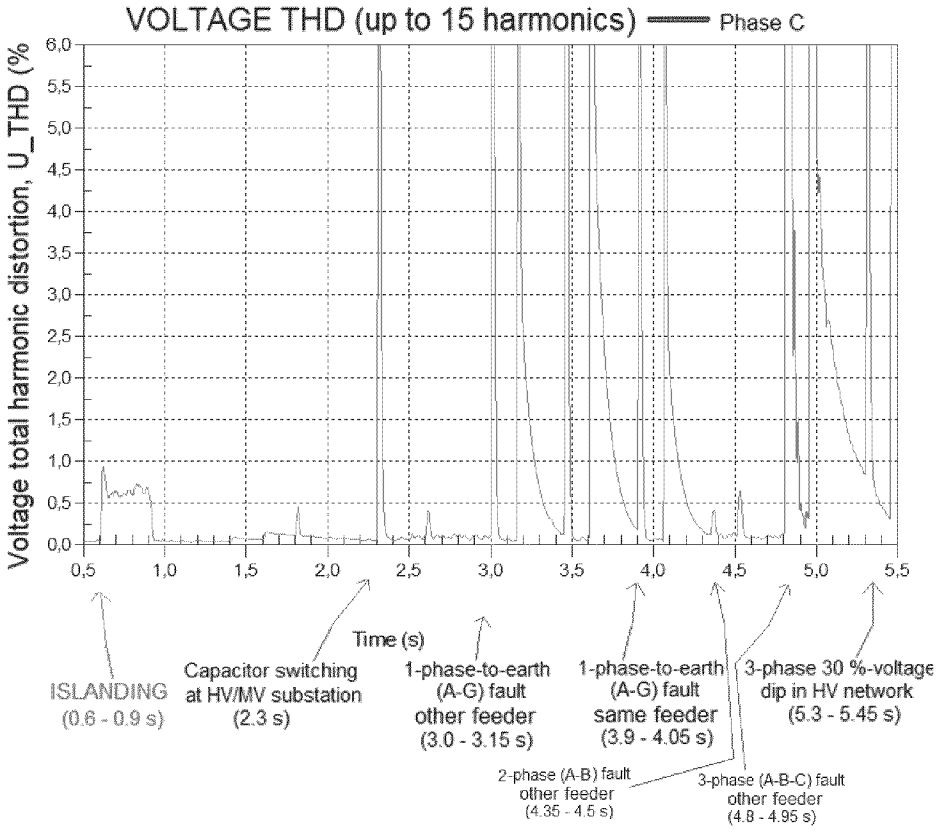

VOLTAGE THD (up to 15 harmonics)
Phase C
Voltage total harmonic distortion, U_THD (%
6,0
5,5
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
Time (s)
ISLANDING
(0.6 - 0.9 s)
Capacitor switching
at HV/MV substation
(2.3 s)
1-phase-to-earth
(A-G) fault
other feeder
(3.0 - 3.15 s)
1-phase-to-earth
(A-G) fault
same feeder
(3.9 - 4.05 s)
3-phase 30 %-voltage
dip in HV network
(5.3 - 5.45 s)
2-phase (A-B) fault
other feeder
(4.35 - 4.5 s)
3-phase (A-B-C) fault
other feeder
(4.8 - 4.95 s)

Fig. 7C

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/056724

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02J3/38
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)
H02J

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JANG S-I ET AL: "An Islanding Detection Method for Distributed Generations Using Voltage Unbalance and Total Harmonic Distortion of Current", IEEE TRANSACTIONS ON POWER DELIVERY, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 19, no. 2, 1 April 2004 (2004-04-01), pages 745-752, XP011109811, ISSN: 0885-8977, DOI: 10.1109/TPWRD.2003.822964	1-6, 8-13,15
Y	page 745 - page 748; figures 5,6,9,11,14	7,14

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[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 May 2013	05/06/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bergler, Christian

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/056724

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	MASSOUD A M ET AL: "Harmonic distortion-based island detection technique for inverter-based distributed generation", IET RENEWABLE POWER GENERATION,, vol. 3, no. 4, 7 December 2009 (2009-12-07), pages 493-507, XP006033911, ISSN: 1752-1424, DOI: 10.1049/IET-RPG:20080101 page 496 - page 500; figures 1,4; table 1 -----	7,14

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