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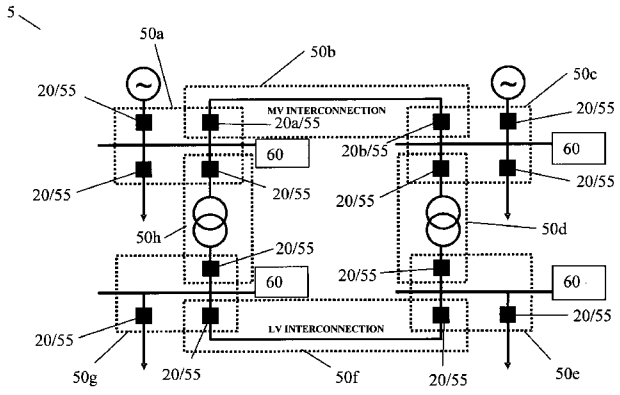


Figure 2

(57) Abstract: A power distribution network comprising a plurality of pre-determined zones, each pre-determined zone being electrically bounded by switches and measurement instruments. The measurement instruments at the electrical boundary of each zone are operable to monitor that zone for faults. At least one switch is operable to selectively isolate at least one pre-determined primary zone in response to a fault in that pre-determined primary zone. At least one switch is operable to selectively isolate at least one larger pre-determined zone containing the faulty primary zone and at least one other zone when the faulty primary zone cannot be isolated.

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Self Organising Unit Protection

The present invention relates to protection for electrical power networks, and in particular self-organising wide area protection.

Background

Electricity supply networks require protection devices to protect against device failures, power surges and leakages to earth. This is particularly true of portable and/or modular networks to which loads, cable circuits and generation devices can be frequently connected and disconnected.

Portable and modular power systems are typically protected using devices that compare a measured electrical current against a user defined threshold value. If the threshold is exceeded, the devices operate to break a circuit and isolate a part of the network. Such devices may include switches and/or relays. The threshold value is predefined, based on knowledge of the prevailing generation capacity and network configuration. The settings of different devices must be selected in such a way that they operate in the correct order to isolate a fault whilst minimising unnecessary equipment disconnections. The protection configuration must also guard against the failure of protection devices by providing backup capability should one or more of these devices fail to operate.

When the configuration of the network is changed (e.g. by adding more dispersed generation), the protection scheme may be unable to guarantee that it will meet these requirements unless the settings of the devices are modified appropriately. For more complex configurations, such as when generators are connected at widely separated points in the power system, or when cables are connected so as to form a ring, existing protection systems may be unable to meet both of these fundamental requirements. These limitations place a constraint on the full exploitation of portable power generation systems since it is necessary to restrict deployed systems to simple pre-designed configurations. These configurations may be inefficient, may also be poorly responsive to operational needs and can be comparatively unreliable.

One type of known protection system is a unit protection system. Unit protection systems operate by comparing currents entering and exiting a protected zone. A protected zone comprises pieces of equipment and cabling bounded by fault-breaking switches and current measurement instruments. For example, a zone may

be a serial cable circuit having a fault-breaking switch at the inlet and outlet of the circuit. This creates a scheme that is inherently desensitised to variations in the current supply to the zone. A suitable bias characteristic can be applied to counter any non-ideal characteristics of instrument components, such as those associated with the effects of magnetic saturation due to external faults resulting in large currents that pass through the zone. The application of unit protection requires that a communications link be provided between the ends of the scheme, and that external backup be included to deal with the failure of unit relays or fault-breaking switches.

In spite of unit protection's accepted desensitisation to the level fault current supply, issues exist with regard to its dependence on the communication of remote measurements and its lack of functionality as a backup for other adjacent relays or zones. Moreover it is, in its existing form, somewhat inflexible to changes in topology as zones are rigidly defined and measured values communicated over dedicated point-to-point links.

Both US 6,347,027 and US 6,697,240 describe electric power distribution systems having automated reconfiguration. These networks describe linking distribution devices, such as substation breakers, reclosing substation breakers and reclosers, by a communications network. The devices share information over the communications network so that the existence of other devices belonging to different networks can be recognised, and allowing more intelligent decision making and cooperation between networks. The shared information includes status indications, control requests and data values. The shared information can be used to modify the protection characteristics of the devices, for example, by reprogramming or reconfiguring a line recloser to operate as a line sectionalizer.

In "A Wide Area Differential Backup Protection Scheme for Shipboard Application", J. Tang and P.G. McLaren, 2005 IEEE Electric Ship Technologies Symposium, 25-27 July 2005, pages 219-224, the authors describe a wide area differential protection (WADP) system for ships. This system uses inner differential rings formed by current transformers around a single component, augmented differential rings formed by expanding an inner ring to its next connect current transformer from both ends, and an outermost differential ring formed by current transformers at the boundary of the protected region such that it covers the whole protected area. The system monitors the outermost differential ring (i.e. the ring covering the whole protected area). A fault anywhere in the system activates this outermost ring. Upon activation of the

outermost ring, a differential search algorithm is used. This searches for a faulty component by forming and searching various inner rings and augmented rings. This process is time consuming, leads to delays in finding and isolating the faulty component and requires significant processing resources.

In "Multi-Zone Differential Protection for Transmission Networks" by K. Kangvansaichol and P.A. Crossley in 2004, Eighth IEEE International Conference on Developments in Power System Protection, 5-8 April 2004, Volume 2, pages 428 to 431, the authors describe the use of a representative data (RD) technique in which if a measurement is lost at a terminal, then Kirchoff's Current Law is used to reconstruct or calculate a signal representative of the measurement using the vector sum of other current measurements. This is then coupled with a tripping priority strategy in which tripping of two neighbouring zones containing a fault is controlled. This works by first tripping the breaker associated with the missing data. Then, if the problem fails to be solved, adjacent zones containing the breaker with the missing data are tripped. The system is controlled by a data management system (DMS). Data collected is fed into the DMS and the DMS applies the RD technique along with graph theory to understand the connection arrangements of the network and generates allow/block signals for each unit protection. This centralised control system leads to delays in isolating the system and is susceptible to breaks in communications. Also there is no back-up protection for loads.

Another protection system is described in "Experimental Examination of Wide-area Current Differential Backup Protection Employing Broadband Communications and Time Transfer Systems", Y. Serizawa, H. Imamura, N. Sugaya, M. Hori, A. Takeuchi, M. Inukai, H. Sugiura, T. Kagami, IEEE Power Engineering Society Summer Meeting, 18-22 July 1999, pp1070-1075. This proposes a wide area backup protection scheme based on the current differential principle. This is a centralised protection system and is in addition to an entirely separate primary protection system. The centralized backup protection waits for the primary protection to fail to operate before taking action.

Summary of Invention

According to a first aspect of this invention, there is provided a power distribution network, the network being divided into zones, each zone being electrically bounded by switches and measurement instruments, the measurement instruments being operable to initially monitor at least one primary zone for faults and the switches

being operable to initially selectively isolate at least one primary zone in response to a fault in the primary zone and further operable to selectively isolate at least one larger zone containing the primary zone and at least one other zone when the primary zone cannot be isolated.

The measurement instruments may be current measurement instruments and/or voltage measurement instruments.

The switches may be adapted to isolate the larger zone at a time delay after a failed attempted isolation of the primary zone.

Portions of the network may be provided with one or more controllers adapted to determine and/or reconfigure zones associated with that portion. The portions may correspond to components of the system, which may include busbars, and/or transformers and/or interconnectors and/or generators and/or loads. The controllers may be adapted to monitor changes in configuration of the network, which may include the connection and/or disconnection of devices. The controllers may be adapted to dynamically determine and/or reconfigure the zones in response to the changes in configuration of the network. The controllers may be adapted to determine local network topography and thereby the zones.

At least one controller may be adapted to determine a status and/or monitor operation of at least one switch and determine and/or reconfigure the zones based on the determined switch status and/or operation. The switch may be a non-fault breaking switch.

At least one controller may be adapted to create and/or determine one or more primary and/or larger zones adjacent to a switch upon opening of the switch; and/or create at least one primary and/or larger zones overlapping a switch upon closing of a switch. The switch may be a non-fault breaking switch.

At least one controller may be adapted to compare the status of at least one switch associated with at least one zone with a predetermined switch status or combination of switch statuses for that zone and may enable zones whose switch statuses match the predetermined switch statuses and/or disable zones whose switch statuses do not match the predetermined switch statuses.

At least one controller may be arranged to determine if at least one non-fault breaking switch has opened, and upon determining that a non-fault breaking switch has opened, create at least one new zone, which may optionally be a primary zone, on one side of a non-fault breaking switch; remove control of at least one fault breaking switch for at least one existing zone; remove an association of at least one measurement instrument associated with the at least one existing zone; and associate a measurement instrument associated with the fault breaking switch with the at least one existing zone.

At least one controller may be arranged to determine if at least one non-fault breaking switch has closed, and upon determining that a non-fault breaking switch has closed, provide control of at least one fault breaking switch for at least one existing zone; associate at least one measurement instrument with at least one existing zone; remove the association of a measurement instrument associated with the non-fault breaking switch with the at least one existing zone; and remove at least one zone, which may optionally be a primary zone, wherein the removed zone is located on one side of the non-fault breaking switch.

The switches may be further operable to successively isolate a hierarchy of consecutively larger zones, each larger zone in the hierarchy containing the primary zone, the hierarchy consisting of tiers of larger zones, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone.

The switches may be operable to isolate at least two tiers of a hierarchy of larger zones.

The switches may be adapted to isolate at least one larger zone of a tier in the hierarchy at a time delay after a failed attempted isolation of a zone of a lower order tier in the hierarchy.

The switches may be adapted to selectively isolate selected larger zones in each tier of the hierarchy. Only one larger zone in each tier may be selected. The larger zone or zones selected for each tier may be those having an internal switch that is not required to isolate the larger zone in two or more component zones of the larger zone or zones. The larger zone selected for each tier may be that having a non-operable switch in all of its component zones.

At least one load attached to the network may be provided with a load backup device adapted to monitor the current flowing to the load and may further be adapted to generate a fault indication in order to isolate at least one zone when an abnormal current is detected.

According to a second aspect of the present invention, there is provided a method for selectively isolating components of a power distribution network, comprising dividing the network into zones, each zone being electrically bounded by switches and measurement instruments, initially monitoring at least one primary zone for faults, operating the switches in order to initially isolate at least one primary zone in response to a fault in the primary zone and, further isolating at least one larger zone containing the primary zone and at least one other zone if the primary zone fails to be isolated.

The measurement instruments may be current measurement instruments.

The method may further comprise isolating the at least one larger zone at a time delay after operating the switches in order to isolate the at least one primary zone.

The method may include monitoring the network for changes in the configuration of the network, which may include connection and/or disconnection of devices. The method may further comprise determining and/or reconfiguring zones associated with a portion of the network. The portions may correspond to components of the system, which may include bus-bars, and/or transformers and/or inter-connectors and/or generators and/or loads. The method may include dynamically updating at least one zone in response to the changes in the configuration of the network. The zones for each portion of the network may be determined using the local network topography.

The method may include determining a status and/or monitoring operation of at least one switch, which may be a non-fault breaking switch, and determining and/or reconfiguring the zones based on the determined switch status and/or operation.

The method may comprise successively isolating tiers of consecutively larger zones in a hierarchy of larger zones, each larger zone in the hierarchy containing the primary zone, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone.

The method may comprise selectively isolating selected larger zones in each tier. Only one larger zone in each tier may be isolated. The larger zone or zones isolated for each tier may be those having an internal switch that is not required to isolate the larger zone in two or more zones. The larger zone or zones isolated for each tier may be those having an internal switch that is not required to isolate the larger zone in two or more component zones of the larger zone or zones. The larger zone isolated for each tier may be that having a non-operable switch in all of its component zones.

The method may comprise monitoring current flowing to at least one load attached to the network and generating a fault indication in order to isolate at least one zone when an abnormal current is detected.

According to a third aspect of this invention, there is provided a protection device for a power distribution network, the protection device having knowledge of protection zones bounded by switches and measurement instruments, the protection device being adapted to initially monitor at least one primary zone of the network and operate the switches to initially selectively isolate the at least one primary zone in response to a fault in the primary zone and further operable to selectively isolate at least one larger zone of the network containing the primary zone and at least one other zone if the primary zone fails to be isolated.

Information on the zones may be stored or embedded within each protection device. The protection device may provided with the zonal information, which may for example be downloaded to it, or may be adapted to dynamically determine the zones. Additionally, the protection device may be adapted to reconfigure the zones in response to changes in the configuration of the network. The protection device may be adapted to communicate with switches and/or at least one measurement device and/or other control devices in order to determine the topology of the network and divide the network into zones based on the determined topology.

The protection device may be adapted to determine a status and/or monitor operation of at least one switch, which may be a non-fault breaking switch, and determine and/or reconfigure the zones based on the determined switch status and/or operation.

The protection device may be adapted to isolate the at least one larger zone at a time delay after operating the switches in order to isolate the at least one primary zone.

The protection device may be adapted to successively isolate tiers of consecutively larger zones in a hierarchy, each larger zone in the hierarchy containing the primary zone, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone. The protection device may be adapted to disable a larger zone in the hierarchy should one or more of its primary zones be isolated.

According to a fourth aspect of the present invention, there is provided a computer program product or a carrier medium containing a computer program or suitably programmed hardware adapted to implement the method of the second aspect or to operate the network according the first aspect or the protection device according to the third aspect.

According to a fifth aspect of this invention, there is provided a power distribution network, having at least one control device adapted to communicate with switches and/or at least one measurement device and/or at least one other control device in order to determine at least part of the topography of the network and divide the network into zones using the determined topography.

Switches and/or measurement devices may electrically bound each zone. The control device may be adapted to initially monitor at least one primary zone for faults using the measurement devices. The operation of the switches may be controlled by the at least one control device, the switches being operable to initially selectively isolate at least one primary zone in response to a fault in the primary zone.

The switches may be further operable to monitor and selectively isolate at least one larger zone containing the primary zone and at least one other zone if the primary zone fails to be isolated. The control devices may be operable to divide the network into larger zones from the determination of at least part of the topography of the network.

The network may be provided with a communications network that is arranged to parallel the power distribution network. The communications network may link at least some of the switches and/or measurement devices and/or control devices.

According to a sixth aspect of the present invention, there is provided a method of dividing a power distribution network into zones, each zone being electrically bounded by switches and measurement devices, the switches being operable to selectively isolate at least one zone in response to a fault in the zone, the method comprising communicating with switches and/or measurement devices and/or other control devices in order to determine at least part of the topography of the network and dividing the network into zones based on the determined topography.

According to a seventh aspect of the present invention there is provided a computer program product or a carrier medium containing a computer program or suitably programmed hardware adapted to implement the method of the sixth aspect or to operate the network according the fifth aspect.

According to an eighth aspect of the present invention there is provided a power distribution network, the network being provided with at least one switch under the control of at least one control device, such that the network is selectively dividable into zones using the switches, the network further being provided with a communications network which parallels the power network, the control devices being adapted to communicate with the switches and/or measurement devices and/or other control devices in order to determine at least part of the topography of the network and thereby divide the network into zones.

At least one control device may determine the topography of the communications network and thereby the power network.

Each of the control devices may maintain a list of adjacent devices and may be further adapted to use the list to determine zones to which it belongs. Each control device may be adapted to detect the connection of new adjacent devices and update its list of adjacent devices accordingly. Each of the control devices may be adapted to communicate its list of adjacent devices to each of the devices on the list.

Each cable connected to the network may be equipped with a device for identifying it to protection devices associated with the part of the network to which it is connected.

The cable identifier may be used to identify the connectivity of the protection device and thereby determine the zones to which it belongs.

Brief Description of Drawings

Various aspects of the invention will now be described by way of example only and with reference to the accompanying drawings of which:

Figure 1 is a circuit schematic of a small scale power system;

Figure 2 is a circuit schematic of the small-scale power system of Figure 1 divided into primary zones;

Figure 3 is a circuit schematic of the small-scale power system of Figure 1 divided into examples of secondary zones;

Figure 4 is a flow chart of a zone configuration process;

Figure 5(a) is a flow diagram of a scheme for tripping the fault-breaking switches of a primary zone;

Figure 5(b) is a flow diagram of a scheme for tripping the fault-breaking switches of a secondary or higher order zone;

Figure 6 is a circuit diagram of a portion of the small-scale power system of Figure 1 divided into primary zones;

Figure 7 is a circuit diagram of a portion of the small-scale power system of Figure 1 divided into secondary zones;

Figure 8(a) is a flow chart of a scheme for use in determining reconfiguration of zones based on operation of non-fault breaking switches;

Figure 8(b) is a flow chart of a first scheme for determining reconfiguration of zones;

Figure 8(c) is a flow chart of a second scheme for determining reconfiguration of zones; and

Figure 8(d) is a flow chart of a third scheme for determining reconfiguration of zones; and

Figure 9 is a schematic of a small-scale power system provided with load backup protection.

Detailed Description of Drawings

System Configuration

Figure 1 shows a circuit schematic of an example of a small-scale power system 5. The power system 5 has generator units 10 and equipment connection points 15 attached via fault-breaking switches 20 to various bus bars such as medium voltage

25 and low voltage 30 bus bars. Non-fault-breaking switches 22 may optionally be placed between the fault-breaking switches 20 and the equipment connection points 15 and/or between the fault-breaking switches 20 and busbars 25, 30.

The fault-breaking switches 20 (otherwise known as circuit breakers) are devices that are intended, designed, constructed or adapted to be controlled to completely interrupt the large current that flows during an electrical fault or short circuit. Fault breaking switches may be mechanical, electronic, or of any other appropriate technology. The non-fault breaking switches 22 are devices that are intended, designed, constructed or adapted to separate an electrical circuit into two or more electrically distinct parts, but which are not intended to interrupt and/or not capable of interrupting the large current that flows during an electrical fault or short circuit (although the non fault breaking switch may or may not be capable of allowing this current to pass through it without interruption). The devices 22 may be capable of interrupting smaller currents associated with the normal operation of the electrical circuit. Non-fault breaking switch 22 may be mechanical, electronic, or of any other appropriate technology.

Several like bus bars 25, 30 may be connected together by interconnectors (e.g. medium voltage interconnector 35 and low voltage interconnector 40), each interconnector 35, 40 being connected to each bus bar 25, 30 via a fault-breaking switch 20a, 20b, 20. Bus bars 25, 30 are connected to different voltage rated bus bars 30, 25 by transformers 45 (e.g. a medium voltage/low voltage transformer), the connection of each bus bar 25, 30 being through fault-breaking switches 20.

Parts of the network 5 or pieces of equipment electrically bounded by fault-breaking switches 20 can be defined as zones 50, 75, as shown in Figures 2 and 3. Measurement apparatus 55 is provided at the boundaries of each zone 50, 75. The measurement apparatus 55 is adapted to measure current characteristics and derive data for use by protection devices 60, such as time-stamped current phasors and plant status data. The measurement apparatus 55 may be integral with the fault-breaking switches 20 as shown or provided separately. Measurement apparatus may also be associated with non-fault-breaking switches 22, either integrally or by separate provision.

Each protection device 60 is associated with one or more busbar 25, 30 in the network 5. The protection devices 60 are adapted to make use of measurements

made by the measurement apparatus 55 at the boundaries of each protected zone 50, 75 for which the protection device 60 is responsible. For each zone 50, 75 in which it participates, the protection device 60 identifies a set of required measurements that are compared to identify a fault in the zone 50, 75. This set is partitioned into those that are obtained from measurement apparatus 55 associated closely with the device for example those at the same geographical location or connected directly to the device ('local measurements') and those that are obtained from measurement apparatus 55 associated with remote devices 60 ('remote measurements'). Each measurement point is designated by a measurement identifier and the protection device 60 with which it is most closely associated.

In an alternative embodiment of the fault detection logic described above, each instance of measurement apparatus 55 is also arranged to measure voltage in addition to the current flowing through a fault breaking switch 20. The measurement apparatus 55 is arranged to calculate the direction of current flow by any suitable means known in the art. The directions of current flow with time stamps are sent to protection devices 60 as described above.

A communications network 65 linking the measurement equipment 55, fault-breaking switches 20 and protection devices 60 is also provided. The data is made available by the measurement devices 55 over the communications network 65 to the protection devices 60. This infrastructure facilitates the remote tripping or closing of fault-breaking switches 20. The communications network 65 has the same topology as the power network 5, for example, by incorporating a communication cable alongside or within each of the power cables. The network may be hard wired or wireless, or a combination of both.

Each device 60 is allocated a communications channel with a measuring device 55 or another protection device 60. In this respect, a channel is just a communications route between two devices 60 or 55 and need not be a dedicated link. Such channels may be formed by any suitable means known in the art such as by packet switching, time division, code division or frequency division. The determination of communication delays to ensure that current phasors are aligned to the same point in time is achieved though the use of continuous monitoring of channel delays using timing information contained within the data packets or, alternatively, by GPS time stamping.

The protection devices 60 communicate with each other over the network 65 in order to determine the topology of the network 5 around them and also to detect any changes in topology. The protection devices 60 use the topology to determine and continually update the zones 50, 75, as well as reconfigure the protection. Each device 60 monitors the communications channel corresponding to each of the available power network connections 70 to determine whether another protection device 20 is connected at the remote end. When the power network 5 changes configuration (or when it is first connected together), the result of this test will change.

Each device 60 is assigned a unique identification. Each device 60 is preconfigured with the identities and interconnection topology of the fault-breaking switches 20 under its direct control. As shown in Figure 4, each protection device monitors devices connected to it. When a new connection is detected, the device 60 establishes communications with the new remote device 60 and exchanges identifying information and information about the topological interconnection of its fault-breaking switches 20. Each device adds this information to a list of adjacent devices 60. Each entry in this list is associated with one or more topologically ordered lists of fault-breaking switches 20 under the control of the device 60 on the list. Conversely, when a communication link to an adjacent device is broken, that device is removed from the list of adjacent devices with a subsequent reallocation of zones.

By continuously monitoring for configuration changes, determining updated topologies and updating the zones accordingly, the system can automatically adapt itself to accommodate the new devices. This is particularly advantageous in portable power networks, for which such network reconfiguration can have a big impact.

When the list of adjacent devices maintained by a device 60 changes, the new list is communicated over the network 65 to each of the devices 60 named on it. On receipt of such a list, the receiving device 60 forwards it to all devices 60 adjacent to it except for the original sender. The list is annotated with the number of times that it has been forwarded in this way since last transmitted by the original sender (the 'hop count'). Each subsequent recipient device 60 forwards the list to its adjacent devices 60 (except the most recent sender where there is only one communication path between the two devices) until the hop count reaches a preset level associated with a desired level of back-up protection. In this way, each device 60 builds a topological

model of the communication network 65 and thus power network 5 in its immediate neighbourhood on the basis of its list of adjacent devices 60 and switches 20.

In an alternative embodiment, each power cable or apparatus 35, 40 and 45 used in the power network 5 is equipped at each end with an identifying device (not shown) for providing an identification that is readable by the protection device 60 associated with the piece of equipment to which the cable or apparatus 35, 40 and 45 is connected. Each cable or apparatus 35, 40 and 45 has a unique identification, which is present at each end. The identifying device can be an RFID tag, or pattern of contacts or holes in the connector, or any other suitable identifier apparent to a person skilled in the art.

When a new cable or apparatus 35, 40 and 45 is connected to a fixed connector 17 associated with a protection device 60, it is identified by the protection device 60, and added to a table of connected cables together with the identity of the fixed connector 17. The protection device 60 broadcasts to all the other protection devices 60 the identity of the newly connected cable or apparatus 35, 40 and 45, its own identity and the identity of the fixed connector 17 to which the cable or apparatus 35, 40 and 45 is attached. Any device 60 receiving such a message that is also connected to the identified cable or apparatus 35, 40 and 45 sends a reply to the originating device 60 identifying itself and the fixed connector 17 under its control to which the cable or apparatus 35, 40 and 45 is attached, together with information about the topological interconnection of its fault-breaking switches 20. The originating device 60 replies with information about the topological interconnection of its own fault-breaking switches 20.

Each device 60 adds the other to a 'table of neighbours', identifying the fixed connector 17 through which the remote device 60 can be reached. Each device 60 communicates the identity of the newly neighbouring device 60 to existing members of its 'table of neighbours', each of which retransmit the notification using a hop counter as described above to ensure the communication reach is appropriate for the required level of backup protection.

When a cable or apparatus 35, 40 and 45 is physically disconnected from a fixed connector 17 associated with a protection device 60, the information relating to that cable or apparatus 35, 40 and 45 is removed from the protection device's table of connected cables, and if the corresponding remote device linked by the cable or

apparatus 35, 40 and 45 is still connected to the network 5, the corresponding device 60 is signalled that the connection has been broken. Both devices 60 remove the entry for each other corresponding to disconnected cable or apparatus 35, 40 and 45 from their table of neighbours. The removed entry is communicated to any remaining devices 60 to which the entry is relevant, which in turn retransmit the notification to their neighbours to the extent required by the desired level of back-up protection. Thus, each device 60 builds a topological model of the communication and thus power network in its immediate neighbourhood on the basis of its list of adjacent devices 60 and fault-breaking switches 20. The topological models produced using the device identifier based embodiment and the cable identifier based embodiment are identical for identical physical power network topologies.

Zoned Protection

Figure 2 shows allocation of primary zones 50 associated with the small scale power system 5 of Figure 1. Primary zones 50 encapsulate specific items of equipment such as cable circuits, bus-bars 25, 30 and transformers 45. A protection device 60 monitors the primary zones 50 of all equipment directly connected to the bus-bar 25, 30 to which it is installed. Consequently, a protection device 60 monitors *N* circuits/transformers, where *N* is the number of connections made to the bus-bar 25, 30, in addition to the bus-bar 25, 30 itself. This gives a total of *N+1* primary zones 50. On sensing a fault condition, the protection device 60 instantaneously signals appropriate fault-breaking switches 20 to open to isolate the faulted primary zone 50.

As shown in Figure 3, secondary protection zones 75 are extensions of the primary zones 50 and provide a first layer of back-up protection. Each secondary zone 75a, 75b encapsulates two primary zones (50a, 50b and 50b, 50c respectively). The protection device 60 associated with each bus-bar 25 monitors at least *N* secondary zones 75 in addition to those primary zones 50 discussed above. The secondary zones 75 operate in a similar manner to the primary zones 50 but with a fixed time delay. This allows the secondary zones 75 to act as a time graded backup for primary zones 50 in case a fault-breaking switch 20 or other protection device 60 fails to operate. Thus, if a fault-breaking switch 20 fails to open in order to isolate a primary zone 25, after the time delay, the fault-breaking switches 20 of a secondary zone 75 containing the problematic primary zone 50 operate to isolate the secondary zone 75 and thereby the primary zone 50 having the defective fault-breaking switch 20. In order to improve selectivity of the isolation, the tripping of a back-up

secondary zone 75 is dependent not only upon the result of the comparison of its boundary currents, but also on a blocking function.

A blocking function is a function that provides for selective operation of only one secondary zone 75 associated with a primary zone 50 having a non-operative fault-breaking switch 20. The blocking function uses the status of a fault-breaking switch 20, that is internal to the zone under consideration to determine which secondary zone 75 is best activated. For example, consider that a fault occurs within primary zone 50b as shown in Figure 2 and that it is not cleared because fault-breaking switch 20a does not open. Without a blocking function, secondary zones 75a and 75b would both trip. However, the problem can be dealt with by operating 75a alone and, therefore, it is preferable that only secondary zone 75a activates. By initiating a blocking function that prevents the tripping of the secondary zone 75b, but permits the tripping of secondary zone 75a in which all of the component primary zones 50a, 50b of the secondary zone 75a contain the non-functioning fault-breaking switch (i.e. 20a), the opening of the fault-breaking switches 20 of secondary zone 75b can be avoided and a greater level of selectivity introduced. By employing such a blocking function, the amount of equipment shut down by operating a secondary or higher order zone is minimised.

In an alternative embodiment of the blocking function, each device 60 periodically determines whether any of the fault-breaking switches 20 associated with it have opened or closed. Where a fault-breaking switch 20 has opened, the protection device 60 identifies those zones 50, 75 within which the switch 20 lies and assigns them as being inactive. When a fault-breaking switch 20 has closed, any inactive zone 50, 75 within which it lies is assigned as active. Messages announcing the change in switch state are sent to all remote devices 60 that participate in the most extensive back-up zones 50, 75 in which the device 60 detecting the change participates, and all topologically intervening devices 60. On receiving such a message, a device 60 determines which (if any) of the zones in which it participates are affected by the change and mark them as active or inactive as appropriate. Primary zones 50 are never marked as inactive.

The concept of the secondary zone can be extended in tertiary or higher order zones to form a hierarchical zoning system. Tertiary zones are allocated to encapsulate three primary zones 50 and provide an additional layer of back-up using a further time delay that is greater than the delay used for the secondary zones 75. A blocking

scheme is used for tertiary zones to improve the selectivity of this layer of backup protection. The logic for operating the fault-breaking switches 20 in each zone 50, 75, including the blocking function, is shown in Figure 5(a) for primary zones 50 and Figure 5(b) for secondary 75 and higher order zones. Use of the blocking scheme becomes more important for higher order zones, as there may be several higher order zones associated with each primary zone. Thus, it will be appreciated that minimising the amount of higher order zones that are activated as back-up to deal with a problem in a primary zone becomes more important as the order of the zones increases.

Additional zone layers can be added and follow the pattern of extending a zone to cover an additional primary zone 50 and having successively longer time delays. In this way, further layers of back-up are provided without the need to provide additional redundancy or back-up resources. The functionality required to realise the additional layers of back-up is simply the additional current comparisons, blocking logic and remote communication and is limited only by the capabilities of the hardware platform used for implementation.

Zone Determination

By communicating between protection devices 60 using the communication network 65, the protection devices 60 act in co-operation with one another such that they can self-organise and determine their role in the protection scheme. Whenever the topological model maintained by a protection device 60 changes, the device 60 uses the new topological model to identify the zones of protection in which the device 60 participates in line with the principles outlined above.

Specifically, each device 60 will define the boundary of each primary zone 50 in which it participates as a set of electrically adjacent switches 20 in which at least one of the switches 20 is closely associated with the device 60. The set of measurements required by the primary zone 50 is defined to be those relating to measurement points 55 which are electrically adjacent to exactly one of the switches 20 bounding the primary zone 50.

Each device 60 will define each secondary zone 75 in which it participates as the union of one initial primary zone 50 in which it participates with one additional electrically adjacent primary zone 50. The device 60 may or may not participate in the additional primary zone. Measurement points 55 and switches 20 at the mutual

boundary of the initial and additional primary zones 50 shall not be controlled or required by the resulting secondary zone 75. The set of switches 20 related to the secondary zone 75 is defined to be the set of switches 20 forming its boundary for which there is at least one electrical path wholly within the secondary zone 75 connecting any switch to any other. The set of measurements required by the secondary zone 75 is defined to be those relating to measurement points 55 which are electrically adjacent to exactly one of the switches 20 in the set of switches 20 related to the secondary zone 75.

Each device 60 will define tertiary and higher order zones in which it participates as the union of one initial zone in which it participates from the immediately lower tier of the hierarchy of zones with one additional electrically adjacent primary zone 60. The device 60 may or may not participate in the additional primary zone. Measurement points 55 and switches 20 at the mutual boundary of the initial zone and the additional primary zone 50 shall not be controlled or required by the resulting secondary zone 75.

The set of switches 20 related to the tertiary or higher order zone is defined to be the set of switches 20 forming its boundary for which there is at least one electrical path wholly within the zone connecting any switch to any other. The set of measurements required by the zone is defined to be those relating to measurement points 55 which are electrically adjacent to exactly one of the switches 20 in the set of switches 20 related to the zone. The device 60 shall not participate in a zone unless it is closely associated with at least one switch 20 at the boundary of the zone, or controls one measurement device 55 required by the zone.

As discussed above, each zone 50, 75 is defined by a set of fault-breaking switches 20 (and their closely associated protection devices 60), which form the boundary of the zone 50, 75. Various tiers of zones 50, 75 in a hierarchy of zones are provided to provide hierarchical back-up capability.

Where a device 60 detects that a non-fault-breaking switch 22a having associated measurement apparatus 55 has opened or closed, it can rearrange primary and secondary zones, as illustrated in Figure 6, Figure 7 and Figure 8(a). This can be done in a number of ways.

Figure 8(b) is a flow diagram of the steps of a first method for reconfiguring the new zones in the event of changes in the network. The first step is to determine the status of one or more non-fault breaking switches. When it is determined that a non-fault breaking switch is opened, new primary zones are created next to the switch; the original primary zone containing the switch is removed; new secondary and higher order zones are created adjacent the switch; and the original secondary and higher order zones are removed. When it is determined that a non-fault breaking switch is closed, a new primary zone overlapping the switch is created; adjacent primary zones are removed; new secondary and higher order zones overlapping the switch are created; and the adjacent secondary and higher order zones are removed.

To illustrate this, consider Figures 6 and 7. When switch 22a opens, primary zone 50i is replaced by new primary zones 50j, 50k having their boundary at the newly opened non-fault-breaking switch 22a, as shown in Figure 6. Secondary zones 75c, 75d are replaced by new secondary zones 75e, 75f having their mutual boundary at the newly opened switch 22a, as shown in Figure 7. When switch 22a closes, primary zones 50j, 50k are replaced by a new primary zone 50i and secondary zones 75e, 75f are replaced by new secondary zones 75c, 75d. Tertiary and higher order zones are treated in the same manner as secondary zones 75c, 75d, 75e, 75f.

Alternatively, the method of Figure 8(c) can be used. The first step is to determine the combination of non-fault breaking switch positions. Then zones for the current combination are identified and enabled. Subsequently any zones not matching the current combination are identified and disabled.

In this case, again with reference to Figures 6 and 7, primary zones 50i, 50j, 50k, secondary zones 75c, 75d, 75e, 75f and analogous tertiary and higher order zones will be determined by device 60 at each moment at which the physical network topology is detected to have changed. For each zone, the required combination of positions of each non-fault-breaking switch 22 having associated measurement apparatus 55 for that zone to be active will be determined. When a device 60 detects that a non-fault-breaking switch 22 has opened or closed, the required positions of switches 22 for all current active and inactive zones in which the device participates will be compared with the actual current combination of positions of switches 22. Those active zones whose required combination does not match the current combination will be made inactive, and those inactive zones whose required combination matches the current combination will be made active.

Another option is illustrated in the flow diagram of Figure 8(d). The first step is to determine the status of non-fault breaking switches. If a switch has opened, a new primary zone is created on one side of the non-fault breaking switch. Trip control of fault breaking switches for the other zones is removed. Also removed are measurements from existing primary, secondary and higher order zones. Once this is done, measurements at the non-fault breaking switch are added to the existing primary, secondary and higher order zones. If a switch has closed, measurements and trip control are added to existing larger primary, secondary and higher order zones. Measurements at the non-fault breaking switch are removed for existing larger primary, secondary and higher order zones. Once this is done, the smaller of the existing primary zones is removed.

In this case, where a device 60 detects that a non-fault-breaking switch 22a having associated measurement apparatus 55 has opened, a new primary zone 50k will be created, and the scope of primary zone 50i will be reduced by removing its association with fault breaking switch 20e and replacing its association with measurement apparatus at switch 20e by an association with measurement apparatus at switch 22a. Secondary zone 75c will have its associations modified in the same manner. Secondary zone 75c will have its associations with fault breaking switches 20c, 20d removed, and associations with measurement apparatus at switches 20c, 20d replaced by an association with measurement apparatus at switch 22a. Tertiary and higher order zones are treated in the same manner as secondary zones 75c, 75d.

When non-fault-breaking switch 22a closes, primary zone 50k will be removed, and primary zone 50j will have its association with measurement apparatus at switch 22a replaced by an association with measurement apparatus at switch 20e, and will gain an association with switch 20e. Secondary zone 75e will have its associations modified in the same manner. Secondary zone 75f will have its association with measurement apparatus at switch 22a replaced by associations with measurement apparatus at switches 20c, 20d, and will gain associations with fault-breaking switches 20c, 20d. Tertiary and higher order zones are treated in the same manner as secondary zones 75e, 75f.

For each zone 50, 75 in which it participates, each protection device 60 identifies the set of measurements that must be compared to identify a fault in the zone 50, 75.

This set is partitioned into those that are obtained from measurement devices 55 closely associated with the device 60 ('local measurements') and those more closely associated with remote devices 60 ('remote measurements'). Each measurement point is provided with an identifier, the identifier including an indication of the protection device 60 to which it is most closely associated with and a measurement identifier. The measurement identifier is used to match measurements received during operation to the current comparisons required for individual zones under the control of the protection device 60.

Each local measurement required by a zone 50, 75 in which a protection device 60 participates may be associated with a list of remote protection devices participating in that zone 50, 75. For each remote device 60 so identified, the local device 60 may transmit a commitment to communicate local measurements to permit the operation of the zone 50, 75. Such a commitment includes the identities of the two devices 60, the identifier of the measurement point and the zone(s) 50, 75 to which it relates. Thus, each protection device 60 may have a list of remote devices 60 to which measurements will be sent, for each measurement apparatus 55 with which it is closely associated.

For each protection zone 50, 75 (of whatever place in the hierarchy), each protection device 60 also has a list of local and remote measurements which will be compared; a list of local fault-breaking switches 20 which will be opened when a fault in the zone 50, 75 is detected; the fixed time delay between detection of a fault and fault-breaking switch 20 operation; a trip timer adapted to record the time elapsed (if any) since a fault was detected, and the status of each zone 50, 75 to which the device 60 belongs, i.e. whether the zone 50, 75 is active as a result of the positions of switches 20, 22 under its control.

Periodically, each protection device 60 obtains measurements of parameters from its local and/or remote measurement devices 55 required by any zone 50, 75 in which it, or any other device 60, participates. The measurements are converted where necessary into the form required for the comparison process, for example into current phasors. The measurement is recorded in the table of measurements for each zone in which the device participates and the measurement is used. The measurement may then be communicated to any other device 60 that is listed as requiring it. Each device 60 also receives and records remote measurements. It monitors its communications interface(s) for any measurement messages addressed to it. When

such a message is received, the measurement is extracted and recorded in the appropriate table of measurements for each zone.

Periodically each device 60 performs a measurement comparison (i.e. a test for a fault, for example a phasor summation) for each active zone 50, 75 in which it participates If a comparison indicates that a fault is present in the zone 50, 75, and the fixed delay for that zone 50 is zero (i.e. the zone 50 is a primary zone), the fault-breaking switches 20 associated with that zone 50, 75 are signalled to open. If a comparison indicates that a fault is present in the zone 50, 75 and the fixed delay for that zone 75 is not zero (i.e. is a secondary or higher order zone), and the trip timer is not running, the trip timer for that zone 75 is started. If the comparisons indicate that the fault is still present in the zone 75, the trip timer for that zone 75 is still running, and the timer has reached a value greater than equal to the fixed time delay, the fault-breaking switches 20 associated with that zone 75 are signalled to open. If a comparison indicates that a fault is not present in the zone 75, and the trip timer for that zone is running, the trip timer is stopped and reset.

Additional Features

The above hierarchical protection system provides back-up protection for the network 5. It can be extended to provide additional load back up protection. As is known, loads connected to a network typically have a specific load protection device. To provide additional protection for the network in the event that the load's own device fails, a load backup device 85 is provided as part of the network that monitors the current flowing to the load.

When the current flowing to the load exceeds a pre-defined value, and following a fixed time delay, the load backup device 85 replaces the current measurement transmitted to the local protection device 60 by the measurement device 55c associated with that load connection with a null-value or any other value that would result in an indication of a fault by protection devices 60. This null value is received at the protection device 60 associated with the bus-bar 110 to which the load 90 is connected and thereby relayed to other protection devices 60 associated with back-up zones 75. The current comparison made by the respective devices 60 will thereby indicate a fault, as the comparison involves a null value. Thus, the primary 50, secondary 75, tertiary and any higher order zones associated with the load 90 activate as necessary as described above in order to provide backup for the load fault-breaking switch 20c.

Figure 9 shows the load back-up protection. In this case, a busbar 110 is supplied by a generator 100 and provides power to a load line 90 that is connected to a load that has its own back up protection device 95. Each is connected to the bus-bar 110 via a fault-breaking switch 20, 20c, each switch being associated with a measurement device 55. Associated with the switch 20c and its measurement device is a load protection device 85 that is part of the network.

As an example, consider the situation when a fault occurs on the load line 90 that causes a leakage to earth 80. For the fault indicated, the load fault-breaking switch 20c should operate first by detecting the large flow of current. However, should it fail to do so, or should the fault-breaking switch 20c fail to interrupt the current, the load backup device 85 operates to destabilize the unit protection by replacing the current measurement sent to the bus-bar unit protection device 60 (and thus to other protection devices 60 monitoring back-up zones) with a null value. This causes the primary zone 50 to trip (and if necessary, the secondary 75 and further zones as described above), thereby providing backup protection to the load fault-breaking switch 20c.

As explained above, the primary 50, secondary 75 and any higher order zones that are allocated during the self-organising process and their operation during reconfiguration are determined based on the status of any internal fault-breaking switches 20. The equipment associated with primary zones can be in an isolated, energized (but unloaded) or interconnected state. Primary zones 50 are monitored regardless of equipment status as the biased current comparison will always be valid, as any charging current is comparatively small. For the case of equipment energized by a single source (e.g. cable circuit or transformer), the operation of secondary and tertiary zones monitored by the protection device 60 located at a bus-bar 25, 30 that is not connected, is blocked due to the open status of the internal fault-breaking switch 20. Thus, the proposed system can manage any topological changes arising due to network reconfiguration through switching leading to the three equipment states given above.

A skilled person would appreciate that modifications may be made to the embodiment described above without departing from the scope of the invention. For example, whilst the system is described as having protection devices 60 associated with each bus-bar 25, 30, a person skilled in the art would recognise that the

protection devices 60 may instead be provided at different levels in the network, for example, the protection devices 60 being associated with a sub-station, or a multi-section switchboard. Furthermore, whilst the fault-breaking switches 20, measurement apparatus 55, protection devices 60 and load backup devices 85 are described as being separate, it will be appreciated that some or all of these may be combined into combined devices. In addition, a skilled person would appreciate that choices are available as to the implementation of the described components, for example, they could be implemented as bespoke hardware components or modules, suitably programmed or adapted generic or multifunctional components or modules or be implemented under the control of a suitably programmed computer system having suitable hardware and software modules.

CLAIMS

1. A power distribution network comprising a plurality of pre-determined zones, each pre-determined zone being electrically bounded by switches and measurement instruments, the measurement instruments at the electrical boundary of each zone being operable to monitor that zone for faults and at least one switch being operable to selectively isolate at least one pre-determined primary zone in response to a fault in that pre-determined primary zone and at least one switch being operable to selectively isolate at least one larger pre-determined zone containing the faulty primary zone and at least one other zone when the faulty primary zone cannot be isolated.

2. A power distribution network according to claim 1, wherein one or more portions of the network are provided with one or more controllers adapted to determine the zones and/or reconfigure the zones in response to changes in the network configuration.

3. A power distribution network according to claim 2, wherein the controllers are adapted to determine local network topography and use this to determine or reconfigure the zones.

4. A power distribution network according to claim 2 or claim 3, wherein at least one controller is adapted to determine a status and/or monitor operation of at least one switch, which may be a non-fault breaking switch, and determine and/or reconfigure the zones based on the determined switch status and/or operation.

5. A power distribution network according to claim 4, wherein at least one controller is adapted to create and/or determine one or more primary and/or larger zones adjacent to a switch, which may be a non-fault breaking switch, upon opening of the switch; and/or create at least one primary and/or larger zones overlapping a switch upon closing of a switch.

6. A power distribution network according to claim 4, wherein at least one controller is adapted to compare the status of at least one switch associated with at least one zone with a predetermined switch status or

combination of switch statuses for that zone and enable zones whose switch statuses match the predetermined switch statuses and/or disable zones whose switch statuses do not match the predetermined switch statuses.

7. A power distribution network according to claim 4, wherein, upon determining that a non-fault breaking switch has opened, at least one controller is arranged to create at least one new zone, which may optionally be a primary zone, on one side of a non-fault breaking switch; remove control of at least one fault breaking switch for at least one existing zone; remove an association of at least one measurement instrument associated with the at least one existing zone; and associate a measurement instrument associated with the fault breaking switch with the at least one existing zone.

8. A power distribution network according to claim 4 or claim 7, wherein, upon determining that a non-fault breaking switch has closed, at least one controller is arranged to provide control of at least one fault breaking switch for at least one existing zone; associate at least one measurement instrument with at least one existing zone; remove the association of a measurement instrument associated with the non-fault breaking switch with the at least one existing zone; and remove at least one zone, which may optionally be a primary zone, wherein the removed zone is located on one side of the non-fault breaking switch.

9. A power distribution network according to any of the preceding claims, wherein the switches are adapted to isolate the larger zone at a time delay after a failed attempted isolation of the initial zone.

10. A power distribution network according to any of the preceding claims, wherein the switches are further operable to successively isolate a hierarchy of consecutively larger zones, each larger zone in the hierarchy containing the faulty primary zone, the hierarchy consisting of tiers of larger zones, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone.

11. A power distribution network according to claim 10, wherein the switches are operable to isolate at least two tiers of a hierarchy of larger zones.

12. A power distribution network according to claim 10 or claim 11, wherein the switches are adapted to selectively isolate selected larger zones in each tier of the hierarchy.

13. A power distribution network according to any of claims 10 to 12, wherein only one larger zone in each tier is selected.

14. A power distribution network according to any of claims 10 to 13, wherein the larger zone or zones selected for each tier are those having an internal switch that is not required to isolate the larger zone in two or more component zones of the larger zone.

15. A power distribution network according to claim 14, wherein the larger zone selected for each tier is that having an internal switch that is not required to isolate the larger zone in all of its component zones.

16. A power distribution network according to any of claims 1 to 15, wherein at least one load attached to the network is provided with a load backup device adapted to monitor the current flowing to the load and further adapted to modify current measurements in order to generate a fault indication in an adjacent segment of network in order to isolate at least one zone when an abnormal current is detected.

17. A method for selectively isolating components of a power distribution network, comprising dividing the network into pre-determined zones, each pre-determined zone being electrically bounded by switches and measurement instruments, monitoring each zone for faults using the measurement instruments at the electrical boundary of that zone, operating the switches in order to initially isolate at least one pre-determined primary zone in response to a fault in that pre-determined primary zone and further isolating at least one larger pre-determined zone containing the primary zone and at least one other zone when the faulty primary zone cannot be isolated.

18. The method of claim 17, including monitoring the network for configuration changes and dynamically determining the zones and/or reconfiguring the zones in response to configuration changes.

19. The method of claim 18, including determining a status and/or monitoring operation of at least one switch, which may be a non-fault breaking switch, and determining and/or reconfiguring the zones based on the determined switch status and/or operation.

20. The method of any of claims 17 to 19, further comprising isolating the at least one larger zone at a time delay after operating the switches in order to isolate the at least one primary zone.

21. The method of any of claims 17 to 20, comprising successively isolating tiers of consecutively larger zones in a hierarchy of larger zones, each larger zone in the hierarchy containing the primary zone, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone.

22. The method of any claim 21, comprising selectively isolating selected larger zones in each tier of the hierarchy.

23. The method of any claim 21, comprising isolating only one larger zone in each tier.

24. The method of claim 21 or claim 23, wherein the larger zone or zones isolated for each tier may be those having an internal switch that is not required to isolate the larger zone in two or more zones.

25. The method of claim 24, wherein the larger zone isolated for each tier may be that having an internal switch that is not required to isolate the larger zone in all of its component zones.

26. The method of any of claims 17 to 25, comprising monitoring current flowing to at least one load attached to the network and generating a fault indication in order to isolate at least one zone when an abnormal current is detected.

27. A protection device for a power distribution network, the protection device being adapted to monitor at least one pre-determined zone of the network for faults using measurement instruments at the electrical boundary of each zone and operate switches to selectively isolate at least one pre-determined primary zone of the network in response to a fault in that pre-determined primary zone and further operable to selectively isolate at least one pre-determined larger zone of the network containing the faulty pre-determined primary zone and at least one other zone if the faulty pre-determined primary zone cannot be isolated.

28. The protection device of claim 27, adapted to determine the zones and/or reconfigure the zones in response to changes in configuration of the network.

29. The protection device of claim 27, adapted to determine a status and/or monitor operation of at least one switch, which may be a non-fault breaking switch, and determine and/or reconfigure the zones based on the determined switch status and/or operation.

30. The protection device of any of claims 27 to 29 adapted to communicate with switches and/or at least one measurement device and/or other control devices in order to determine the topology of the network and divide the network into zones based on the determined topology.

31. The protection device of any of claims 27 to 31, wherein the protection device is adapted to isolate the at least one larger zone at a time delay after operating the switches in order to isolate the at least one primary zone.

32. The protection device of any of claims 27 to 31, wherein the protection device is adapted to successively isolate tiers of consecutively larger zones in a hierarchy, each larger zone in the hierarchy containing the primary zone, the larger zones in each tier containing at least one zone from a preceding lower order tier and at least one further zone.

33. A power distribution network having at least one control device adapted to communicate with switches and/or at least one measurement device and/or at least one other control device in order to determine at least part of the topography of the network and thereby divide the network into zones, each zone being electrically bounded by switches and/or measurement devices, the control device being adapted to initially monitor at least one primary zone for faults, the operation of the switches being operable by the at least one control device to initially selectively isolate at least one primary zone in response to a fault in the primary zone.

34. A power distribution network according to claim 33, wherein the switches are operable to selectively isolate at least one larger zone containing the primary zone and at least one other zone if the primary zone fails to be isolated.

35. A power distribution network according to claim 34, wherein the switches are operable divide the network into larger zones from the determination of at least part of the topography of the network.

36. A power distribution network according to any of claims 33 to 35, wherein the power distribution network is provided with a communications network that is arranged to parallel the power distribution network.

37. A power distribution network according to any of claims 33 to 36, wherein the communications network links at least some of the switches and/or measurement devices and/or control devices.

38. A method of dividing a power distribution network into zones, each zone being electrically bounded by measurement instruments and switches operable to selectively isolate at least one zone in response to a fault in the zone, the method comprising communicating between switches and/or measurement devices and/or other control devices in order to determine at least part of the topography of the network and thereby divide the network into zones and dividing the network into zones based on the determined topography.

39. A power distribution network having at least one switch under the control of at least one control device, such that the network is selectively dividable into zones using the switches, the power distribution network further being provided with a communications network which parallels the power network the at least one control device being adapted to communicate with the switches and/or measurement devices and/or other control devices in order to determine at least part of the topography of the network and thereby divide the network into zones.

40. A power distribution network according to claim 39, wherein the at least one control device determines the topography of the communications network and thereby the power network.

41. A power distribution network according to claim 39 or 40, wherein each of the control devices maintains a list of adjacent devices and is adapted to use the list to determine zones to which it belongs.

42. A power distribution network according to claim 41, wherein each control device is adapted to detect the connection of new adjacent devices and update its list of adjacent devices accordingly.

43. A power distribution network according to claim 41 or claim 42, wherein each of the control devices is adapted to communicate its list of adjacent devices to each of the devices on the list.

44. A power distribution network according to claim 39, wherein each cable connected to the network is equipped with a device for identifying it to protection devices associated with the part of the network to which it is connected.

45. A power distribution network according to claim 44, wherein the cable identifier is used to identify the connectivity of the protection device and thereby determine the zones to which it belongs.

46. A computer program or computer program product adapted to implement the method of any of claims 17 to 26 or 38 or to operate the network according to any of claims 1 to 16 or 27 to 37 or 39 to 45.

47. A carrier medium containing a computer program product according to claim 46.

48. Hardware programmed with the computer program of claim 46.

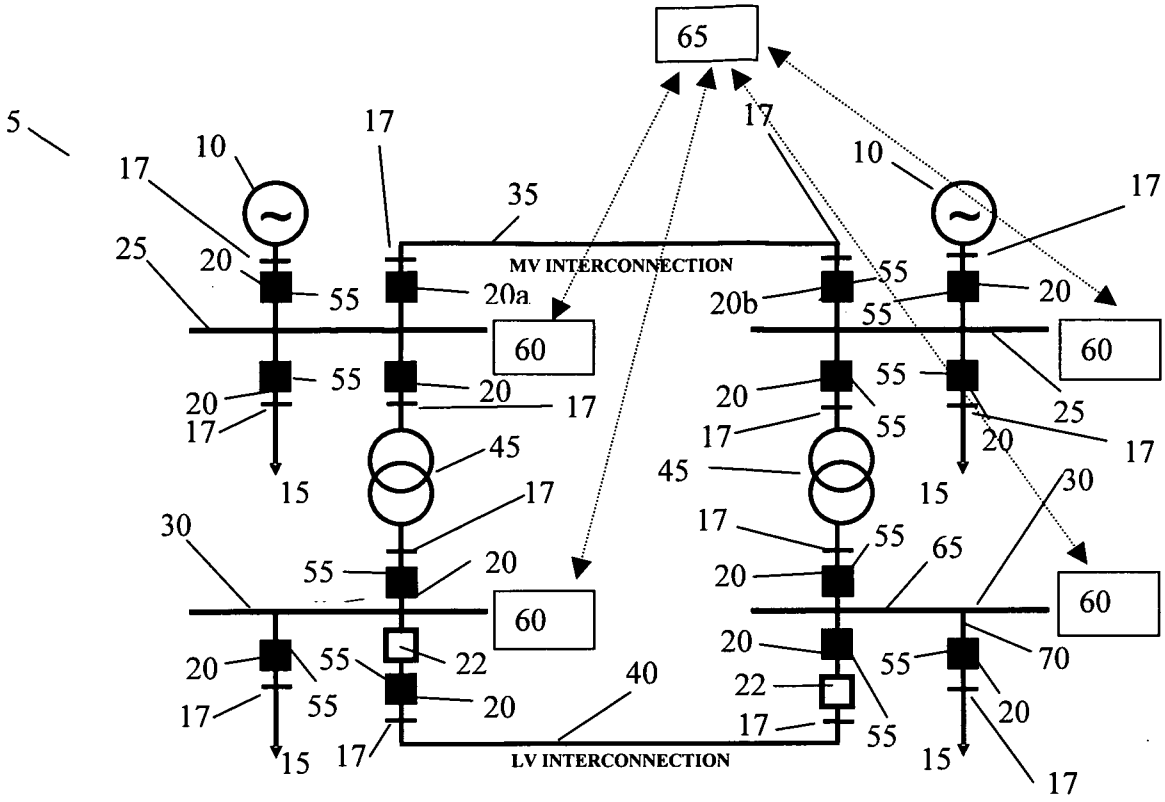


Figure 1

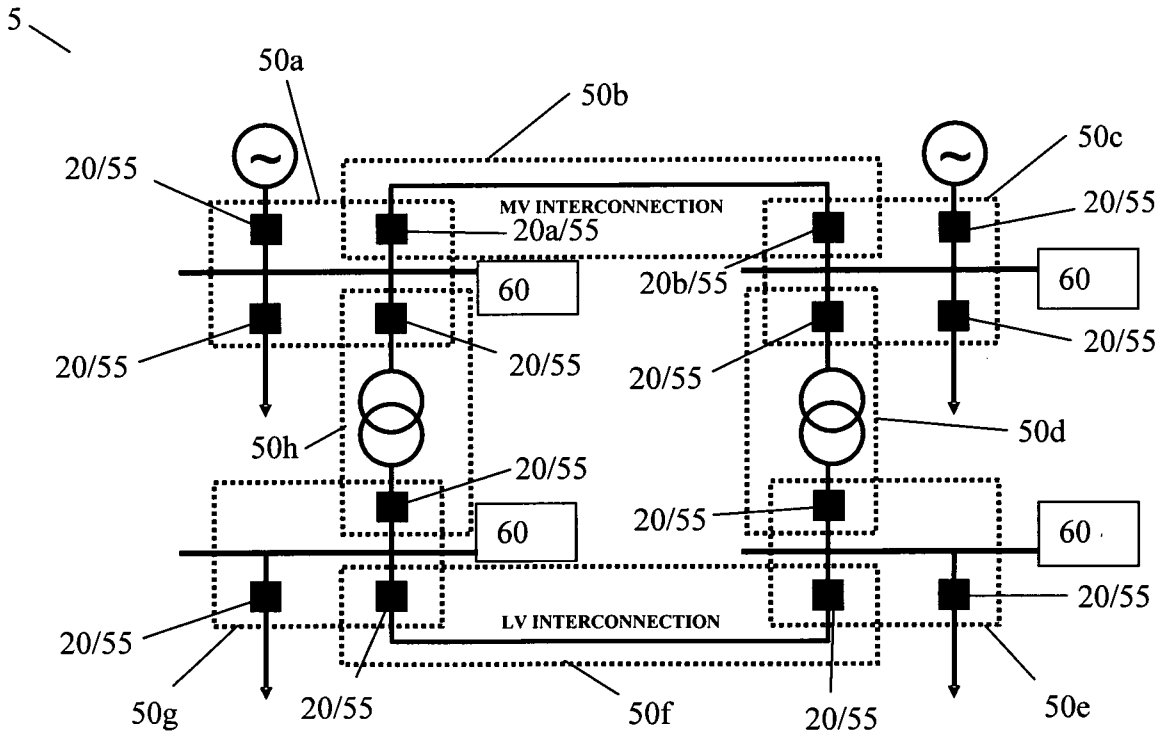


Figure 2

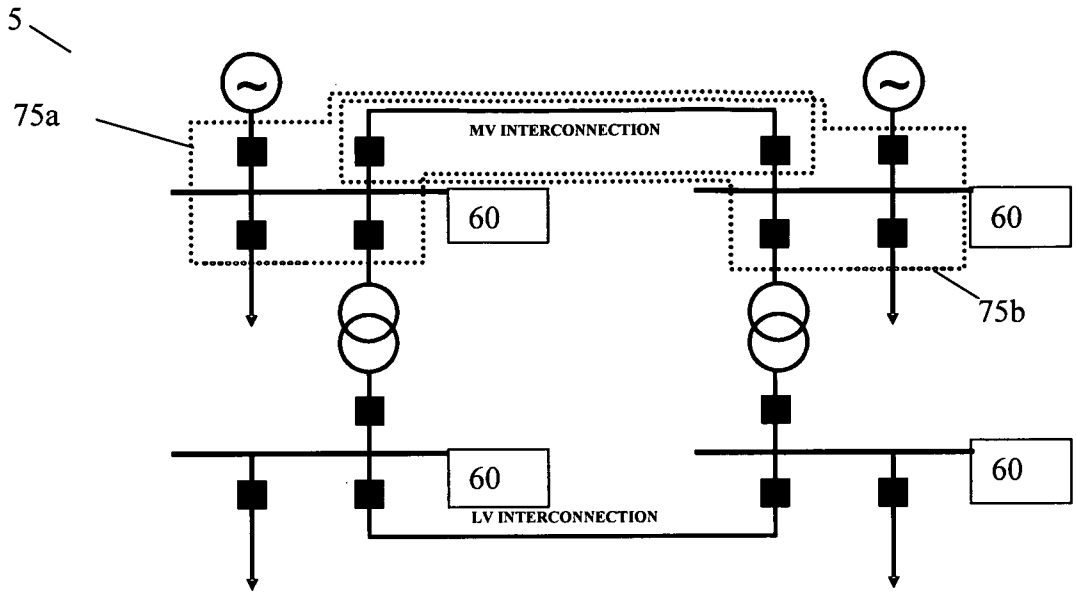


Figure 3

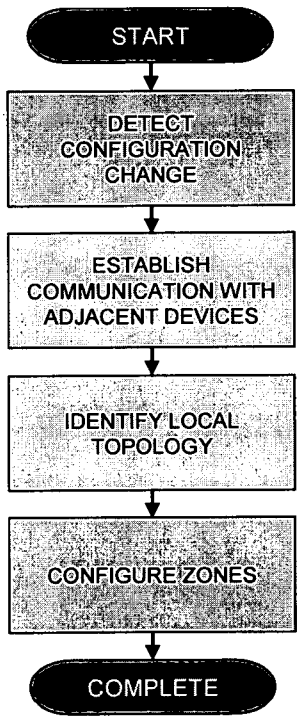


Figure 4

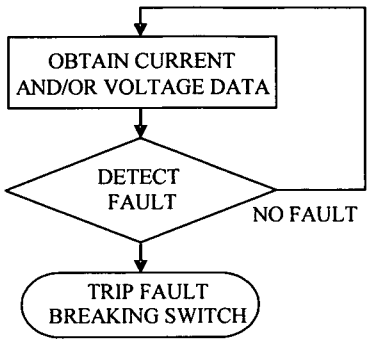


Figure 5(a)

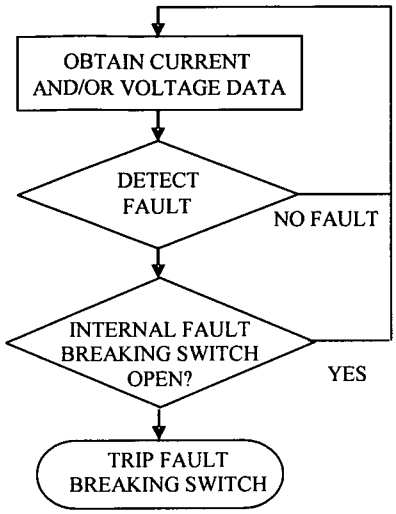


Figure 5(b)

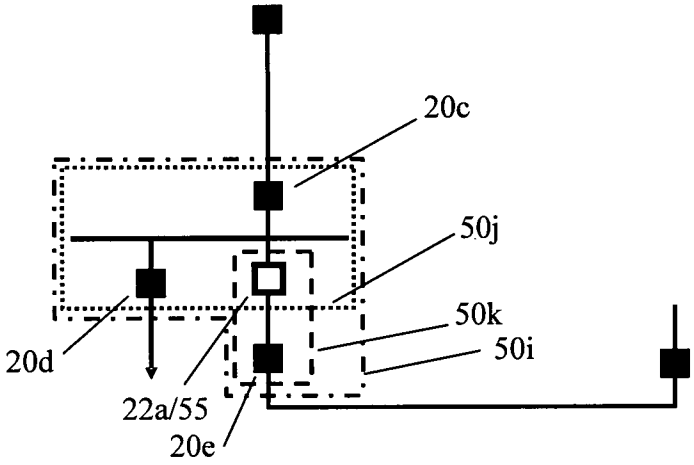


Figure 6

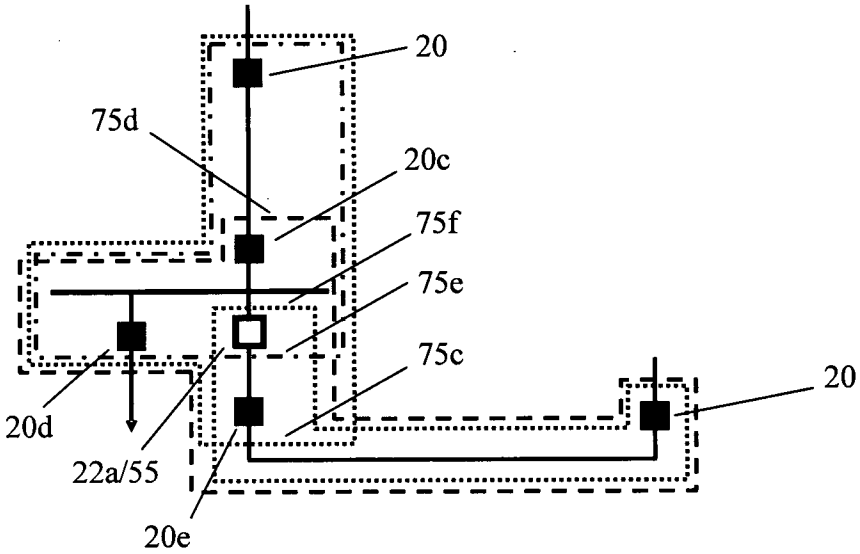


Figure 7

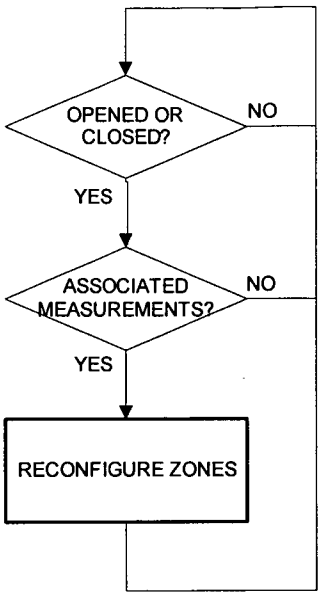


Figure 8(a)

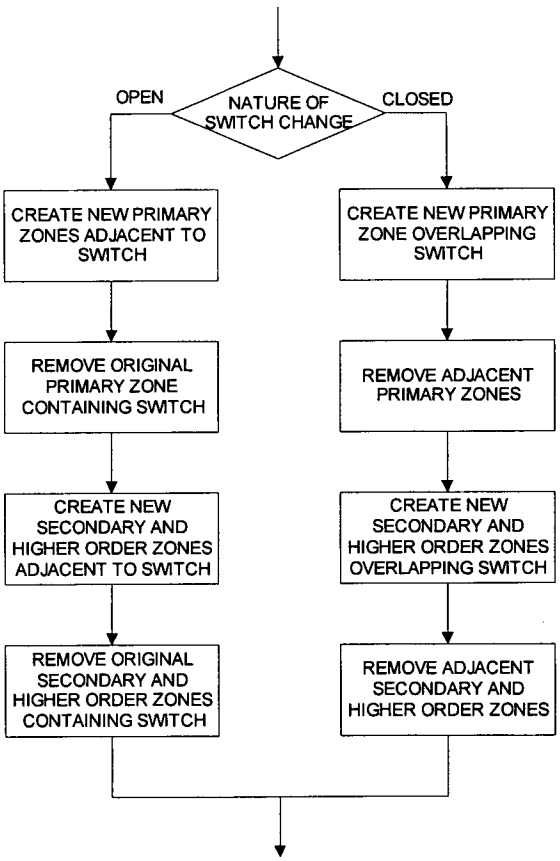


Figure 8(b)

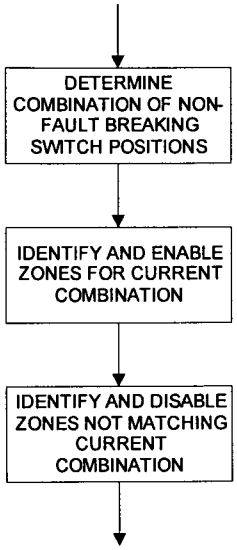


Figure 8(c)

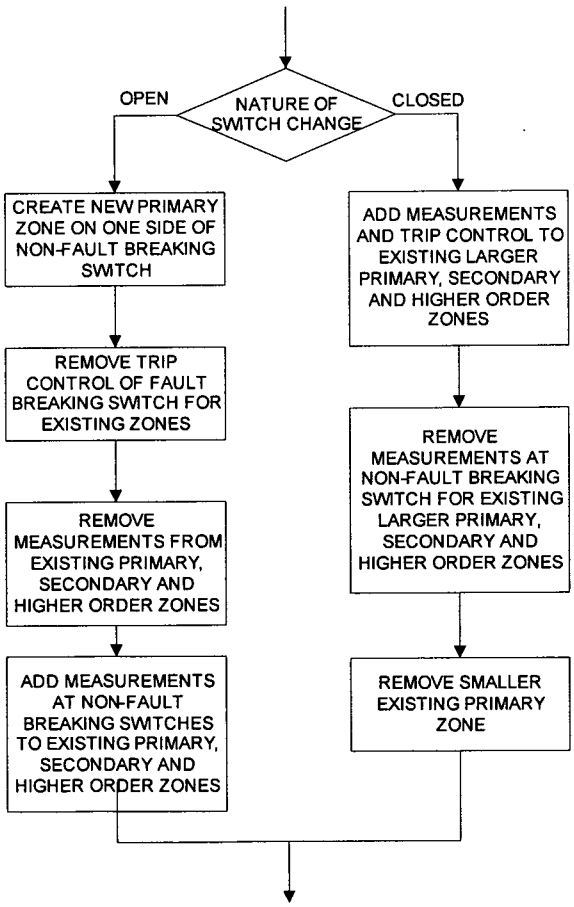


Figure 8(d)

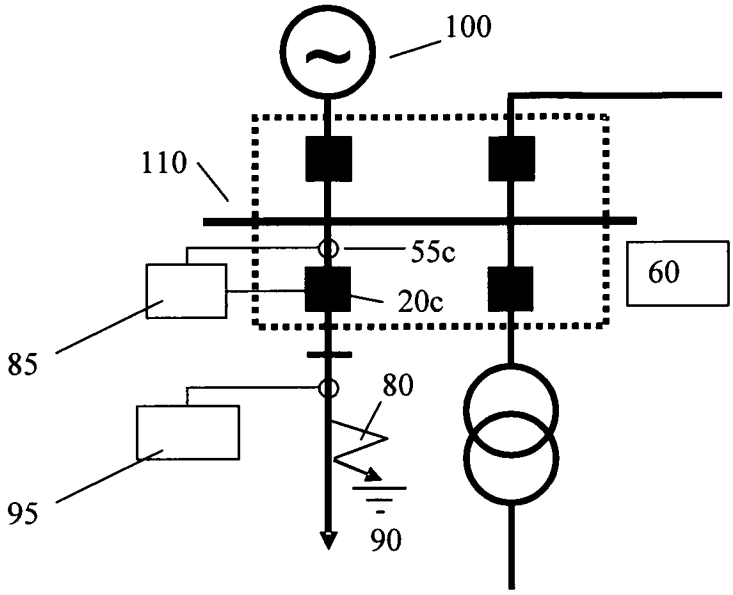


Figure 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/000959

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02H7/26

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 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 practical, 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	US 4 689 708 A (HAGER HELMUT [CH] ET AL) 25 August 1987 (1987-08-25) column 2, line 64; figure 1 column 8, line 28 - column 9, line 12	1-48
X	US 2004/130837 A1 (PAPALLO THOMAS F [US] ET AL) 8 July 2004 (2004-07-08) paragraphs [0081] - [0090]; figures 5,6	1,17
A	US 6 411 865 B1 (QIN BAI-LIN [US] ET AL) 25 June 2002 (2002-06-25) column 3, line 30 - line 52; figures 1-3	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 August 2009	26/08/2009

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	Colombo, Alessandro

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2009/000959

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 0201324 A2	03-01-2002
		ZA 200300375 A	22-01-2004