NEW FUNCTIONALITIES AND FEATURES OF IEDS TO REALIZE ACTIVE CONTROL AND PROTECTION OF SMART GRIDS

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ABSTRACT

Intelligent electrical devices (IEDs) used for protection and control of distribution networks are gaining increasing importance on the way towards Smart Grids. In this paper the main functionalities and features required from future IEDs to enable the realization of active network management and protection schemes for the future Smart Grids are described and highlighted with example simulation results from a few cases. Special attention will be paid to distributed generation (DG) interconnection and MV feeder IEDs.

INTRODUCTION

To fulfill increasing energy efficiency and reliability requirements active control and management of distribution networks, including control of distributed energy resources (DER), will play a key role in future Smart Grids. Real-time information about distribution network status (voltage, frequency etc.) is required and information about distribution network status for control and monitoring purposes will be obtained in the future increasingly from sensors across the network through high-speed wireless 4G networks and optical fibers which can also be integrated in power cables.

In the future it is likely that these different active network management functionalities like voltage control, island operation coordination, minimization of losses etc. will be realized through centralized solutions at HV/MV (MV level management by DMS/SCADA or station computer or IED) and MV/LV (LV level management by IED, RMU or MicroSCADA) substations (Fig. 1).

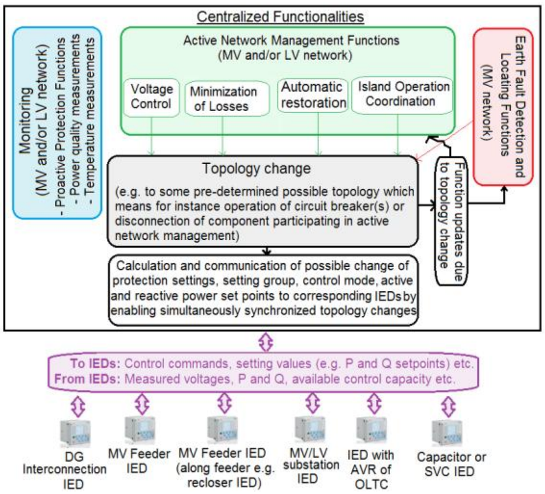


Figure 1. An example of some possible centralized functionalities at HV/MV and MV/LV substations.

Therefore, intelligent coordination hierarchy between management of MV and LV level will be required as well as the consideration of dependencies between active network management and protection functionalities to create future-proof solutions for future Smart Grids. Also centralized monitoring, earth-fault locating or measurement reporting functionalities are becoming more and more important from asset management point of view (Fig. 1).

In this paper, the purpose is to describe and define some of the new functionalities and features required from future IEDs to enable the realization of active network management and protection schemes for the future Smart Grids. Special attention with a few simulation examples will be paid to MV feeder and distributed generation interconnection IEDs (Fig. 1 and 2).

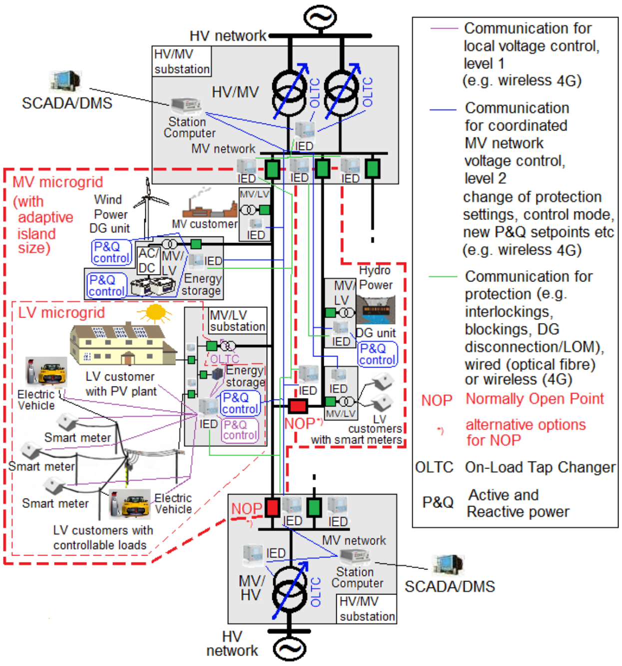


Figure 2. Smart Grid compatible IEDs with appropriate communication capabilities and new functionalities will play key role in enabling future active network management and protection concepts.

DG INTERCONNECTION IED FUNCTIONS AND REQUIRED SMART GRID FUNCTIONALITY

Utility grid stability supporting functions

Previously DG units were usually required to be disconnected during faults, but due to constantly increasing number of DG units connected into the distribution networks this is not feasible anymore because it would lead to loss of large amount of generation after voltage or frequency disturbances. Therefore, it has also become important to require utility grid stability supporting functionalities from these units by local grid codes. Currently all countries have their own specific grid codes, but for example in Europe ENTSO-E grid code RfG [1] is under development and the objective is to have more consistent DG interconnection requirements in Europe in the future.

DG interconnection IEDs may in the future play an increasingly important role in active network management if utility grid stability supporting functionalities required by current and future grid codes are fulfilled by utilization of corresponding DG interconnection IED functionality. DG interconnection IEDs could e.g. by usage of high-speed communication send active and reactive power (P and Q) control commands to DG unit control in case of disturbances i.e. frequency and/or voltage deviations to fulfil the required fault-ride-through (FRT) requirements.

One of the basic functionalities in future DG interconnection IEDs will also probably be settable low-voltage-ride-through (LVRT) curve for under-voltage protection to fulfil DG FRT requirements defined at national grid codes. In Fig. 3 Finnish FRT requirements for 0.5 – 100 MW generator units regarding to voltage, frequency and rate-of-change-of-frequency (*df/dt*) deviations are presented. These FRT requirements must be taken into account when determining the corresponding protection settings for DG units. Currently in Germany grid codes also require “Directional Reactive Power Undervoltage Protection” (Q->&U<) functionality from DG interconnection IEDs to ensure that the generators which are required to ride through the faults do not decrease the voltage even more during voltage drops by absorbing reactive power.

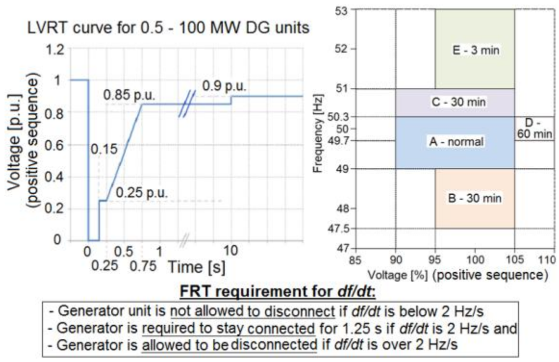


Figure 3. FRT requirements in Finland for 0.5 – 100 MW generator units regarding to voltage, frequency and *df/dt* deviations. [2]

MV network active management supporting functions

The key functionalities of DG interconnection IEDs to support the active management of MV network includes for example islanding (loss-of-mains) detection, synchrocheck and steady state voltage control functions. State estimation of MV networks with increased amount of DG units could also be improved by voltage, *P* and *Q* measurement from DG IEDs as well as from other essential locations.

Active MV network voltage control

Active voltage level control of MV networks is important during steady state conditions to enable better utilization of the line capacity and to avoid unnecessary or over-dimensioned network infrastructure upgrades. Centralized voltage control in MV level should be well co-ordinated with possible LV network active voltage control schemes with such hierarchy that voltage deviations are first tried to be fixed locally as close as possible to the location of the voltage violation. Active LV level voltage control could be realized at a MV/LV substation with centralized functionality integrated. For example future MV/LV substation IEDs could co-ordinate the operation of controllable distribution transformers (OLTC) or centralized energy storage together with active and reactive power control of DG units as well as with controlling charging of electric vehicles. It has been stated for example in [3] that most of LV network voltage violations today could be avoided with controllable distribution transformers.

Centralized voltage control both in MV and LV level should be also linked with asset management functionalities like network losses minimization and possible minimization/restrictions in number of daily tap changer operations in controllable HV/MV or MV/LV transformers. Centralized voltage control also must adapt to topology changes in MV network (e.g. radial => meshed, large DG unit connected => disconnected etc.).

In the future DG interconnection IEDs could participate in active MV network voltage control and one key standard in which DG unit control issues are included is IEC 64850-7-420. In [4] it has also been highlighted that that the focus of Edition 1 of IEC 61850-7-420 has been mainly on different DER technologies and IEC TC57, WG17 is currently working on the development of a generic DER interface model which should include information about the nominal available active and reactive power, the currently available active and reactive power as well as set points or other control mechanisms. By utilization of that kind of system view described in [4] it could be possibly to enable also the participation of clusters with many DER units in a standardized way into active voltage control of future distribution networks.

Islanding detection

One essential functionality required from DG interconnection IEDs is reliable detection of islanding. Non-detection zone (NDZ) near power balance situation and unwanted DG trips due to other network events (nuisance tripping) have been the major challenges with traditional, passive local islanding detection methods like for example frequency (f), *df/dt*, vector shift (VS) or voltage (*U*).

Even if high-speed communication is used as primary islanding detection method passive local islanding detection method is still needed as a back-up. Also, if the amount of DG units in distribution networks continuously increases in the future, also the risk of power balance situations and therefore risk of possible operation in NDZ of traditional islanding detection methods will increase. In addition, in new grid codes these same parameters *f*, *U* and *df/dt* are increasingly used to define FRT requirements to enable utility grid stability supporting functionality of DG units as described earlier in the paper. Therefore, the usage of these parameters for reliable and selective, e.g. with auto-reclosing schemes, islanding detection will become even more difficult than today. Although the trend in new grid codes is to require FRT capability from DG units and possibly also allow island operation, there still is a need to reliably detect the islanding situation to make correct operations e.g. change the setting group of DG interconnection IED or change control principles and parameters of DG unit.

Due to the above mentioned issues, in [5] a new multi-criteria-based islanding detection algorithm based on multiple simulations has been developed. This new islanding detection algorithm is able, based on local measurements, to detect very fast and selectively islanding situations in a perfect power balance without NDZ. The new multi-criteria algorithm measures the changing natural response of the network due to islanding based on a change in the voltage total harmonic distortion (THD) of all the phase components ΔU_{THD15a}, ΔU_{THD15b}, ΔU_{THD15c} and a change in the voltage unbalance ΔVU as well as utilizes intelligently the available fault detection information which ensures a rapid and reliable islanding detection (Fig. 4). With the new islanding detection algorithm no nuisance tripping is likely to occur due to other network events or disturbances and it is not dependent on the DG unit type.

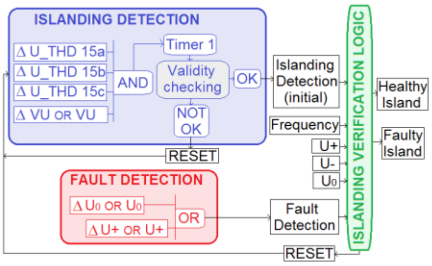


Figure 4. Basic principle of the proposed multi-criteria-based algorithm for islanding detection in distribution networks.

In following are some short examples of PSCAD simulation results which were done with the study network shown in Fig. 5 are shortly presented.

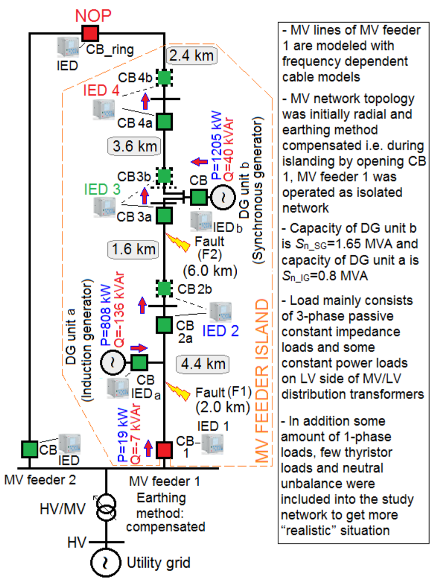


Figure 5. Studied MV network used in PSCAD simulations.

In Fig. 6 islanding simulation results are presented. Islanding happens with the power balance situation (i.e. active and reactive power flow through CB 1 before islanding) shown in Fig. 5 at t=10.0 s by opening circuit breaker CB 1 at the beginning of MV feeder 1. In this case the synchronous generator based DG unit is assumed to change control mode from P&Q -control to speed control after islanding detection with small time delay and this mode change at t=10.2 s also affects the frequency and voltage behavior from that point forward. It can be seen from Fig. 6c) and d) that based on fixed frequency and voltage protection settings which also take into account FRT requirements of grid codes it is impossible to detect islanding fast enough. However, the benefit of using the voltage THD and voltage unbalance together as part of multi-criteria based islanding detection algorithm (Fig. 4) can be clearly seen from Fig. 6 a) and b). Islanding detection based on multi-criteria algorithm can be done very fast, in less than 150 ms, even in power balance situation.

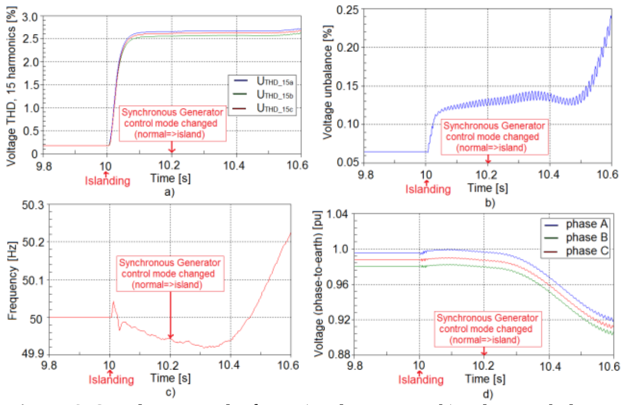


Figure 6. Simulation results from a) voltage THD, b) voltage unbalance, c) frequency and d) voltage behavior after islanding at t=10.0 s with study case shown in Fig. 5.

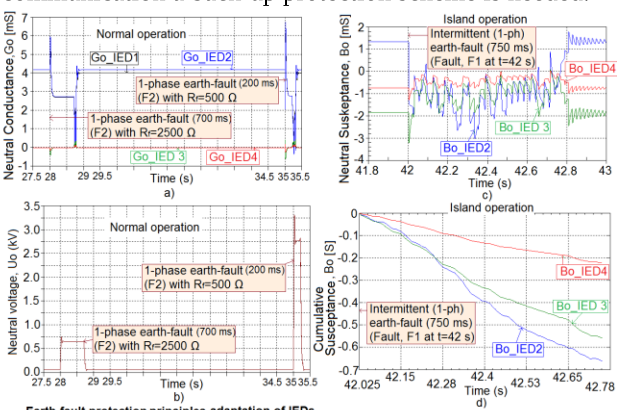
FUNCTIONALITY NEEDS OF MV FEEDER IEDS TO SUPPORT ACTIVE NETWORK MANAGEMENT

Protection principles and settings adaptation to topology changes

In the future both short-circuit and earth-fault protection settings of MV feeder IEDs must adapt to changes in network topology resulting from increased utilization of active distribution network management schemes. First of all in future distribution networks, due to bi-directional power flows, protection naturally needs to be directional. Secondly, the operation speed requirements for the protection of Smart Grids are quite high to be able to minimize the number of customers affected by different faults and disturbances.

From the point of view of MV feeder IED short-circuit protection settings, the most challenging are changes in the short-circuit level due to topology changes like for example large DG unit connected ⇔ disconnected, radial MV feeders ⇔ meshed feeders, utility grid connected ⇔ island operated or due to automatic load restoration when the normally open point (NOP) in a meshed distribution feeder is automatically moved for load restoration purposes following a fault. To support improved supply reliability, to deal with topology changes and disconnect faulted section very rapidly, distance and differential protection with high-speed communication based blocking schemes will be utilized increasingly in the short-circuit protection of future Smart Grids. In reality the required future performance for transmitting blockings and voltage and current samples from sensors could be achieved by utilization of 61850 GOOSE and SV services and possibly also more and more with wireless 4G technologies. From MV feeder IEDs earth-fault protection point of view, it is essential that their setting groups/settings and protection principles can also adapt to changes in MV network earthing method e.g. when changing from centrally compensated utility grid connected operation to isolated island operation. As part of the developed adaptive protection concept it also needs to be defined which parts of the logic related to it will be centralized and de-centralized in IEDs.

In the following a few earth-fault simulation results (Fig. 7) based on the study network shown in Fig. 5 are presented as an example. In the study network it is assumed that there are multiple protection zones which are protected with CBs and corresponding MV feeder IEDs (IED 2, 3 and 4) along the MV feeder (Fig. 5). The number of CBs (Fig. 5) available to protect the MV feeder zones will naturally affect the utilized protection scheme blocking logic and number of unsupplied customers i.e. supply reliability. The operation time settings of short-circuit and earth-fault protection must be selective with DG unit FRT settings during normal operation and during island operation for example earth-fault protection operation time also needs to be very fast to be able to maintain stability in healthy part of the island and therefore in addition to using high-speed communication-based blocking between IEDs, the operation time could be e.g. dependent on neutral voltage (U_o) level (Fig. 7 e). For possible problems with availability and speed of available communication a back-up protection scheme is needed.



Earth-fault protection principles adaptation of IEDs

	NORMAL (compensated)		ISLAND (whole feeder) (isolated)		ISLAND (part of the feeder) (isolated)	
	Primary	Back-up (e.g. if comm. is lost)	Primary	Back-up	Primary	Back-up
IED$_a$	U_o	-	U_o	-	-	-
IED$_b$	U_o	-	U_o	-	U_o	-
IED1	G_o	U_o	U_o *)	-	-	-
IED2	G_o	U_o	B_o	U_o	U_o *)	-
IED3	G_o	U_o	B_o	U_o	B_o	U_o
IED4	G_o	U_o	B_o	U_o	B_o	U_o

*) In open connection point no time delay i.e. only indication to station computer or SCADA

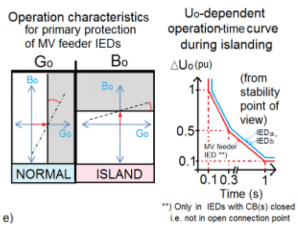


Figure 7. Simulation results about earth-fault protection measurements in a)-d) and in e) some example principles/characteristics for earth-fault protection adaptation of IEDs (Fig. 5).

Neutral admittance (Y_o=I_o/-U_o=G_o+jB_o) based protection is used in the simulation example (Fig. 7), because it is one of the most promising earth-fault protection principles to be utilized in the future distribution networks [6]. During normal (utility grid connected) operation the parallel resistance in the centralized compensation unit was constantly connected and the protection of MV feeder IEDs was based on the fundamental frequency component of neutral conductance G_o and after islanding earth-fault protection was changed to be based on fundamental frequency component of neutral susceptance B_o or U_o depending on island size with U_o being used as a back-up protection in all IEDs within the island (Fig. 7 e).

On the other hand, with the new method presented in [7] it is possible to achieve functionality for directional earth-fault protection of future Smart Grids by utilizing the operational characteristics of multi-frequency neutral admittance protection, together with cumulative phasor summing. This means that the same characteristic based on both G_o and B_o is always valid and primary protection principle of IEDs (Fig. 7 e) is not required to be adaptive.

Synchronized connection functionality to support topology changes

In the future MV feeder IEDs like DG interconnection IEDs need to have synchrocheck or synchronized connection functionality to enable active changing of network topology (Fig. 1). Synchronized re-connection of island operated MV feeder back to utility grid means that the voltage level, phase angle and frequency difference across open CB are between predefined limits before re-connection. Phase angle difference over open CB between two separate networks is traditionally controlled with rotating synchronous generator based DG units by the speed control and voltage level by the reactive power control of the DG unit.

Also, during normal operation synchronized connection may be required e.g. when typically radially operated MV network is changed into a meshed network e.g. in Fig. 5 closing a CB_ring in order to maximize DG penetration and network capacity utilization avoid possible voltage violations as well as possibly also minimizes network losses. To be able to achieve smooth and synchronized connection of MV feeders it should be ensured before closing e.g. CB_ring in Fig. 5 that voltage and phase angle difference across CB_ring are small enough. If required conditions are not met, then centralized functionalities (Fig. 1) can be utilized to correct the differences under the set limits e.g. by affecting reactive power Q flow in MV feeders.

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