COORDINATION OF INTERFACE PROTECTION SYSTEMS FOR DG APPLICATIONS IN MV DISTRIBUTION NETWORKS

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ABSTRACT

The Dispersed Generation (DG) is a form of production based either on renewable energy sources (such as wind and solar photovoltaic) or on conventional energy (such as small gas engines, tipically CHP). In the near future, the growing concern for environmental issues as well as for the security of the supply system is expected to lead to the development of local renewable DGs connected to the distribution network, both Medium Voltage (MV) and Low Voltage (LV) system, which has been designed to host only passive users. Such network architecture, chosen when DG was rare, today can be considerably impacted for operation, control, protection and reliability issues.

INTRODUCTION

The reliability of protection systems that equipped DG may lead to local issues for the Distribution System Operator (DSO), related to QoS (islanding of DG; failures in automation systems). These problems become more critical in case of reverse power flows, from downstream to the main system, that is due to a huge percentage of DG plants. Focusing on these local issues, during the islanding operation a portion of the distribution network (which is isolated from the main system) is energized by the DG plants connected. If the production and consumption within the island find an equilibrium point, the islanding operation can become permanent and new accidental voltage and frequency values are reached. Whilst in case of significant unbalance between load and generation, the island usually collapses (after a temporary islanding transient). Islanding entails problems for power quality, safety, automatic reclosing operation and automation. In the Italian distribution grid, automatic reclosing represents the first level of network automation in order to improve the continuity of supply. It consists in an autoreclosure predefined time: during the dead time the majority of the line faults are cleared (i.e. self clearing or transient faults). Anti-islanding protections have to be introduced for disconnecting DG in a very short time, in compliance with automatic reclosing cycle (O - 400 ms - C) on the Italian MV system [3]. Such a protection/automation scheme is aimed at ensuring higher levels of power quality: in case of non-permanent faults, only a transient interruption is perceived by customers. The anti-islanding protection techniques can be divided into three categories, as explained in [1]: passive methods, active methods and communication-based methods. The passive systems, consisting of protection relays installed at the DG's Point of Common Coupling (PCC), are widely used in the Italian system [4] [5], as in most EU systems.

PASSIVE ANTI-ISLANDING PROTECTIONS

Voltage and frequency relays are adopted in the Interface Protection System (IPS) of the active users. These relays are installed at the DG premises, and are designed to disconnect DG from the grid in particular network conditions (basically, in case of loss of mains, LoM, due to a fault). In order to avoid islanding operation and eliminate DG plants before first fast reclosing. Generally, IPSs have very narrow settings (in terms of voltage/frequency permitted operation) and trip very fast (in theory, the trip is instantaneous to permit a successful fast reclosure): these characteristics aim at ensuring high levels of continuity of supply, as prescribed by the relevant national regulations. These protections, like all other passive methods (e.g. ROCOF and vector shift [1]), are unable to detect islanding conditions with a small power mismatch. In this situation frequency and voltage oscillations are close to the nominal values and they are not sufficient to guarantee relay's operation. In this case a Non Detective Zone (NDZ) appears; it indicates the limited reliability of the IPS in case of islanding. The size of the NDZ depends on the protection system in terms of tripping time, settings thresholds and performance of measurement equipment [1]. To obtain a small voltage/frequency NDZ (and to reduce the possibility of islanding operations) it is necessary to chose an IPS with a short tripping time and high sensitive settings. But IPS with a short tripping time and high sensitive settings (based on passive algorithms) are prone to

nuisance trippings. They occur when protection doesn't distinguish voltage and frequency oscillations due to the islanding operation from other events (e.g. disturbances in the transmission network, faults in adjacent feeders, sudden load changes): frequency values very close to 50 Hz are possible also if no Loss of Main (LoM) appears.

Nuisance tripping implies, problem also for transmission networks operation (global issues). In particular, DG doesn't support network in case of transmission disturbances, when frequency can depart significantly from the nominal value. DG units should remain connected in order to sustain voltage and frequency in case of transmission accidents. The phenomenon can trigger a chain reaction with further loss of generation and a possible network collapse. These events (frequency transients on the transmission network, unescapably followed by a massive loss of DG units), have already happened in recent cases of transmission accidents (Italy - September 28th 2003; UCTE - November 4th 2006). Nowadays, similar transmission accidents could lead to dramatic consequences (e.g. continental blackouts) due to the level of DG penetration reached in the last few years. The solution for this problem would be to use IPS with wider settings that unfortunately will lead to a large voltage/frequency NDZ with the increase of possible islanding operations.

INNOVATIVE IPS: SELECTING LOCAL FAULTS AND TRANSMISSION EVENTS

The coordination of passive methods requires a trade-off between selection of islanding condition (due to faults on the distribution network) and detection of systems events (due to a disturbance on the transmission network).

As stated before, unwanted islanding and nuisance tripping are phenomena closely related to IPS and to the relevant settings. Therefore, settings and tripping time could be defined w.r.t. two different criteria:

- short tripping time and high sensitivity settings, that imply a small voltage/frequency NDZ (according to the reclosing cycle chosen by each different DSO), in order to detect islanding as fast as possible in most of the power system conditions (reliability improvement in case of islanding);
- long tripping time and low sensitivity settings, that imply a large voltage/frequency NDZ in order to avoid unwanted tripping in case of transmission accidents.

The issue of automatic frequency disconnection of installed DG plants has recently (July 2011) been brought to the attention of EU by ENTSO-E. They highlighted that, in several European countries, connection standards applicable to DG plants have been or are still specifying that such generators automatically disconnect from the grid whenever the system frequency reaches 0.2 or 0.3 Hz deviations from the value of 50 Hz. This is a clear risk of an instantaneous generation loss far in excess of the 3000 MW generation loss "ride-through" design limit for the Continental European system, with an increase the risk of extended blackout. ENTSO-E encouraged the national Energy Regulators to facilitate the timely implementation of remedial actions. For this reason, the Italian Electrotechnical Committee (CEI) has recently defined special requirements for DG connected to distribution networks (Standard CEI 0-16:2012 [2], approved by Italian Energy Regulator). The most important innovation regards the IPS for DG units connected to MV networks.

According to this new regulation, all DG plants must be designed to face both local and global issues related to the IPS and to ensure the disconnection of DG units when LoM occurs. DG units connected to the distribution network have to operate if the voltage is between 85% and 110% of the rated level and the network frequency is between 47.5 Hz and 51.5 Hz (these values are consistent with IPS low sensitive settings).

In order to ensure the proper functioning of IPS with respect to the security of transmission networks and the safety, reliability and continuity of service of distribution networks (and of active users), it is necessary to adopt an innovative logical scheme that allows the IPS to discriminate between failures on the distribution network (islanding events) and disturbances on the transmission networks, as shown in Fig. 1. In order to reach high reliability levels (a fail-safe operation) the proposed architecture is able to operate with and without communication.



Fig. 1. IPS operation logic scheme.

IPS operation with a communication system

A novel strategy for IPS operation, that can overcome local QoS issues as well as global issues, is based on a suitable communication system. This solution is capable of protecting distribution networks and DG units from islanded operation, without the need of dangerous overfrequency/underfrequency settings.

In more detail, when communication is active, a low sensitivity setting profile of voltage/frequency protections is enabled in IPS (f.i. 47.5 - 51.5 Hz,), together with transfer trip, in order to disconnect DG only if LoM (or an extreme transmission network incident) occurs. Moreover, with this protective strategy, nuisance tripping due to faults on MV adjacent feeders or disturbance on transmission networks are avoided and DG may contribute to recover emergency conditions of the whole systems.

IPS local operation

Unfortunately, active users are not yet linked with Primary Substation (PS) and the transfer trip can't be implemented, at least in a short-time perspective. In particular, it is worth to motivate that the communication channel has to provide a limited latency in order to be effective. In order to host further renewable energy in the existing distribution systems it is necessary to improve the local operation of IPS, activated when the communication channel is unavailable. In this case, the disconnection of DG for an extreme transmission network incident is guaranteed by IPS wider settings. The wider settings also avoid nuisance tripping due to disturbance on transmission networks. During a fault on distribution networks, the disconnection of DG is guaranteed by IPS high sensitivity frequency settings (49.8 to 50.2 Hz); the relevant activation is achieved by means of one of the following functions (voltage unlock, no direct trip):

- residual overvoltage protection (59.N) to detect phase to ground faults;
- negative-sequence overvoltage protection (59.V2) to detect two-phase faults;
- positive-sequence undervoltage protection (27.V1) to detect three-phase (and two-phase) faults.

In addition, in case of faults on the distribution network, the disconnection of DG is also guaranteed by IPS high sensitivity voltage settings: overvoltage protection (59); undervoltage protection (27); residual overvoltage

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protection (59.N).

In this way the IPS will be able to recognize variations in frequency due to the LoM and to separate DG plants from network in a short time (before the first fast reclosing in order to avoid an out-of-synchronism reconnection).

The main reason for implementing the voltage unlock on IPS is related to the need of discriminating MV events from all other events. To investigate this possibility, it is convenient to define two kind of events on distribution networks, different from islanding, as described below.

- Local events: faults located in the same feeder of the DG connection, for which IPS has to trip in a short period of time.
- External events: faults outside the DG's feeder (typically faults on transmission networks and faults on adjacent feeder), DG has to remain connected (no IPS tripping).

The proper operation of voltage unlock is ensured only if appropriate settings for the relays are applied: finding suitable settings for voltage unlock is a challenging task.

IPS SETTINGS: STUDY CASE

The purpose of the study is to carry out a detailed analysis to verify the voltage unlock function proposed to identify the situations driven by MV faults wrt the ones derived by HV events.

Discriminating between HV and MV events

The first step in order to coordinate the voltage unlock relay is to define a suitable setting for 27.V1, that is able to discriminate between faults on transmission network and faults on distribution network. In Italy since the beginning of 2006, all VQ parameters indicated in EN 50160 are monitored on a sample of buses, belonging to transmission and distribution networks: from this point on, the focus is mainly on the HV monitoring system (MONIQUE, [6]). Among the data collected in 2010, Table 1 reports the average number of voltage dips due to poly-phase faults measured per voltage-quality recorder (VQR). These figures are given per class of duration and residual voltage, according to EN 50160:2010; we are only interested in voltage dips with duration less than 200 ms (after this value the protection 27 trips, and there is no interest in investigating the performance of voltage unlock).

Residual voltage [%]	Number of dips [20 ÷ 200 ms]
90 > u > 80	27
80 > u > 70	10
70 > u > 40	8
40 > u > 5	3
5 > u > 0	0

Table 1. Average data for voltage dips recorded on transmission networks.

The analysis of these values shows that a 27.V1 relay's voltage setting equal to 0,4 p.u. avoids the trip of the IPS for the 94% of the faults on the transmission network.

MV simulations

After this preliminary choice, the second step of the analysis consists in assessing the possibility of using the voltage unlock relay threshold with the goal to discriminate faults on the feeder where DG is connected from faults on adjacent feeders. We exploit the DIgSILENT Power Factory package capability for the simulation of electromechanical transients (RMS models) of a realistic Italian radial structure distribution network, in order to study the oscillations of frequency and voltage at the PCC of DG units. The study case networks are composed by eleven radial feeders (Vn = 10 kV); the primary substation is connected to 120 kV transmission system through two transformers (16 MVA) in parallel with vector group Yny. DG units are connected in four feeders: the photovoltaic power plants are connected to the grid through static components, whereas all other generators are modeled with synchronous machines. Photovoltaic generators operate at unitary power factor (without a voltage regulation); in case of no voltage at PCC the power injected to the grid is null. Synchronous machines have an automatic voltage regulator; frequency control is not adopted (in the short simulation period considered it would not operate). Loads are modeled as constant impedance; overcurrent protections are installed at the top of each outgoing feeder.

Three-phase, two-phase and single-phase to ground faults are simulated at feeder *FD4*, *FD10* and *FD11* in three different positions (Fig. 2): first bus, last bus and in the middle of the feeder in term of electrical distance. A total of 27 simulations are carried out and the performances of each IPS before the first automatic reclosing (400 ms) are analyzed.



Fig. 2. MV network model and fault locations.

In Fig. 3 the voltage and frequency oscillations measured at the PCC of DG unit DG_{11}_1 are shown for threephase fault at the end of Feeder 11 (position $P3_{11}$, local event). The fault occurs at 0.1 s and the disconnection of the faulted feeder by means of the overcurrent protection occurs at 0.246 s (origin of the islanding). After the fault the voltage goes beyond the 27.V1 threshold and restrictive frequency threshold 81.S1 are activated. Thanks to narrow frequency settings, the generator is separated at 0.379 s (0.2 s after the fault event); similarly, DG_{11}_2 is separated from the grid and the islanding operation of Feeder 11 is extinguished before the automatic reclosing.

Now the external event is investigated. The under voltage measured at the DG_1O_1 's PCC lasts till the opening of the fault feeder. Because of the high electrical distance between the DG unit and the short circuit, the PCC voltage drop is not enough to trigger the 27.V1 and IPS continues to operate with permissive frequency threshold; anyway, frequency oscillations are low and DG unit is not disconnected from the grid. Fig. 4 shows the voltage and frequency oscillations at DG_PS_1's PCC for three-phase fault at the top of Feeder 11 (position $P1_11$, external event). This short circuit occurs very close to the PS and, because of the small electrical distance between

the fault and the PCC, voltage drop at the DG unit is enough to trigger the 27.V1 unlock.



Fig. 3. 3Ph fault at $P3_{11}$ - positive sequence voltage (above) and frequency at DG_{11} 's PCC (below).

Furthermore, the frequency oscillation exceeds the restrictive setting 81>.S1 and the power plant is disconnected even if the fault is located in an adjacent feeder (i.e. nuisance tripping).



Fig. 4. Fault at P1_11 positive sequence voltage (above) and frequency at DG_PS_1's PCC (below).

The result summary, which includes three-phase, twophase and single-phase to ground fault simulations, is reported in Table 2; for each fault, the performances of the IPS located in each DG unit's PCC are investigated.

Fault	Relay's proper functioning (internal events)	Nuisance unlock activation (external events)	Nuisance tripping (external events)
3 ph	YES	YES	YES
2 ph	YES	YES	NO
1 ph	YES	YES	NO

Table 2. Result summary for MV faults.

The results show that IPS installed in an isolated neutral MV system presents a not effective 59.N voltage un-lock: in case of single-phase to ground fault the residual voltage reaches the same value in the whole MV network and the activation of restrictive setting can occur even for events far from the PCC. Concerning the single phase to ground faults, The same results can be achieved if the star point of the HV/MV transformer located in the PS is

connected by a Petersen coil. Anyway, in all cases in which restrictive frequency thresholds are activated for MV external events the probability of nuisance tripping increases.

CONLCUSION

The proposed protection scheme introduces an improvement in the IPS's local operation. Even if a complete coordination is not possible, nuisance tripping of DG will be significant reduced. The three-phase fault is the most critical short circuit for the protection selectivity: in case of faults close to the PS, DG units connected to adjacent feeders may be disconnected.

The innovative IPS operating in local mode is reliable in case of islanding events, i.e. a narrow NDZ is guaranteed. It gives benefits to the DSO, because there is no islanded feeded portion, and to the DG owners, because the fast generator disconnection avoids dangerous out of phase reclosures. Critical conditions of power balance between load and generation may happen in the island: even a narrow NDZ of the IPS can become ineffective.

The main objective of the IPS proposed in the new Standard CEI 0-16:2012 is to avoid an islanding operation of a portion of the distribution network, and to avoid nuisance tripping in case of external events on the transmission network even if the selectivity at distribution level is not complete, as obtained in some simulated cases, the transmission network security is still guaranteed (DG is disconnected) and the system stability is not compromised (only loss of generation located under one PS may occur).

A complete coordination is not achievable by means of local information: a trade-off seems to be an inescapable fact. Only a remote control of IPS by exploiting a proper communication network (ICT) in the perspective of smart grids will allow a complete solution of the studied issue.

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