DISPERSED GENERATION IN MV NETWORKS: RELIABILITY OF PASSIVE ANTI-ISLANDING PROTECTION METHODS

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ABSTRACT

The growing development of Dispersed Generation (DG) asks for new management of distribution networks. In particular the DG determines different power flows along distribution feeders giving rise to new issues in protection systems. This paper addresses the issues of the Italian anti-islanding protection systems coordination. The aim is to evaluate the most used passive methods performances in case of network disturbances. On the basis of the results new schemes will be proposed to reduce nuisance tripping of anti-islanding protections.

INTRODUCTION

In Italy Dispersed Generation (DG) denotes generation plants with rated power up to 10 MW, typically connected to medium voltage (MV) and low voltage (LV) distribution networks. This new form of generation allows the use of renewable resources, that are spread on the territory, reducing the use of fossil fuel; on the other hand DG power plants entail power injections in the distribution networks, actually designed to be passive systems, i.e. not able to receive high amounts of generated power.

One of the most important issues is the unwanted-islanding event that is related to possible problems in the actual protection reliability and in network automation.

The term "islanding" indicates an independent operation of a distribution network section that is disconnected from the main grid and that continues to be energized by the DG units. In this scenario DG continues to supply the separated grid with voltage and frequency oscillations within predefined thresholds. Usually an islanding occurs after operation of the electric protection system (e.g., in case of faults). Consequently, a transient of voltage and frequency arises and, after this transient period, the islanded grid can reach a new steady state (i.e. permanent islanding) or, in some circumstances, collapses (after a temporary islanding). Actually the protections installed at Point of Common Coupling (PCC) of the generator are, in most cases, based on local measurements of voltage and frequency oscillation, therefore their reliability depends on two main factors: a) real and reactive power imbalance between load and generation prior to islanding (i.e. power flow between the islanded portion and the rest of the system) and b) the network response. The former is the most crucial factor: the mismatch in real and reactive power between load and generation directly influences voltage and frequency variations [1].

This phenomenon (i.e, the occurrence of an islanding of a portion of MV/LV distribution network) is considered undesirable due to the lower power quality and safety, but especially because out of phase reconnections of islanded network and failures of fault clearing procedures (reclosing cycle of line protection and/or automation procedures) may occur [2]. In fact, it's worth noting that automatic reclosing represents the first level of network automation, and has been introduced for improving the continuity of the supply.

Consequently, it is necessary to introduce anti-islanding protections for disconnecting DG in a very short time, taking into account the typical reclosing cycle (O-400 ms CO-30 s CO-70 s CO-70 s C) on Italian MV network [3].

The most common anti-islanding methods, widely used also on the Italian system, are the passive ones, based on local measurements from protection relays installed at the DG's PCC [5][6].

PASSIVE ANTI-ISLANDING PROTECTIONS

The paper aims to analyze the performance of passive anti-islanding protection schemes which represents the methods actually used in the Italian electrical system.

In the Italian context voltage and frequency relays are used. The national standard CEI 0-16 imposes threshold settings and a maximum tripping times (Tab. 1), in order to eliminate DG units in a very short time after islanding separation and before fast reclosing.

Protection	Setting	Maximum tripping time
Maximum voltage - 59	1.2 p.u.	170 ms
Minimum voltage - 27	0.7 p.u.	370 ms
Maximum frequency - 81>	50.3 Hz	170 ms
Minimum frequency - 81<	49.7 Hz	170 ms

Tab. 1: Voltage and frequency relay settings

The Italian connection standard (Norma CEI 0-16 [7]) imposes a maximum tripping time, that includes protection operating time and switch operating time. The maximum tripping time of protection 27 is 370 ms[1] is achieved using an intentional delay; whereas the other protections may be considered instantaneous. The frequency thresholds, very close to the nominal frequency (50 Hz), are a particular feature of Italian electrical system: these values allow to disconnect DG units in a very short time after an islanding event in order to avoid critical conditions - out of phase - during automatic fast reclosing operation; at present time, this happens after 400 ms from the first Circuit Breaker (CB) tripping[2].

However, those protections and other passive methods widely adopted (including ROCOF and vector shift, based on additional computations of zero crossings [7]), aren't able to detect islanding with a small power mismatch allowing a wide Non Detective Zone (NDZ) (Fig. 1).

In this situation frequency and voltage are stable and their variations aren't sufficient to guarantee relay's operation [4][5]. The NDZ may allow islanding, at least momentarily; in case of perfect load-generation balance (in real and reactive power) the islanding will be permanent. Of course the size of the NDZ depends on the protection system in terms of tripping time, settings thresholds and performance of measurement equipment.

In [2] intentional anti-islanding operations are simulated in several conditions of power flow of the "islanded" feeder before the opening of the Circuit Breaker (CB) on top of the line: considering Italian settings (Tab. 1) voltage relay never operates whereas frequency relay detects islanding if real power imbalance is higher than +18 % or lower than -15 %.

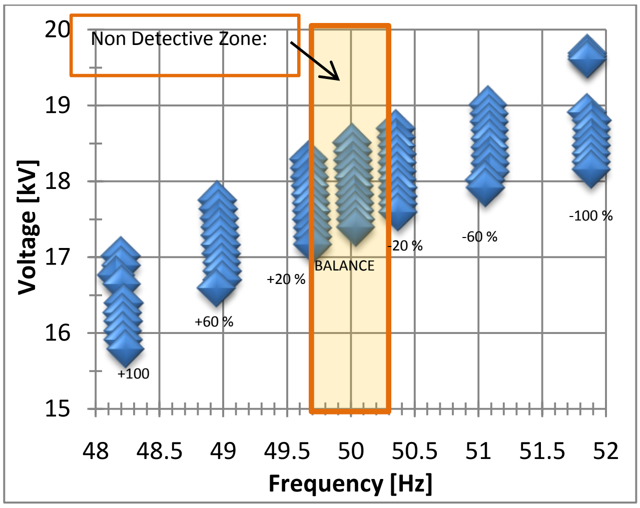

Fig. 1: Non Detective Zone of voltage and frequency relays

1 To avoid an unwanted disconnection of the generator in case of voltage dips caused, for instance, by polyphase faults on a different MV feeder (adjacent feeder).

A second significant problem is represented by unwanted (nuisance) tripping: islanding algorithm is not able to distinguish voltage/frequency variations due to islanding operation from external events (e.g. disturbances in the HV network, faults in adjacent feeders, sudden load changes). Nuisance tripping is a phenomenon closely related to anti-islanding protections and their coordination.

As a consequence of nuisance tripping, the following problems may arise.

- Economic impact on producers due to the loss of produced energy. Although DG plants are designed in order to minimize out-of-service time, the loss of production may be significant.
- Dispersed generation doesn't support network in case of external disturbances. DG units should remain connected in order to sustain voltage and frequency in case network disturbances (e.g. for fault in an adjacent feeder, load variations, frequency transients in HV grids). The phenomenon can trigger a chain reaction with further loss of generation and a possible network collapse. [9]
- DG plants are connected to the distribution network directly or by a static converter. In the first case synchronous machine and gas turbines are usually adopted and unwanted tripping can create mechanical stress resulting in a reduction of the lifetime of the plants.

Finally, re-configuration of feeders or of part of feeders for operation needs have to be considered. Disturbances to voltage and frequency, in these cases, may be considerably lower than in case of a fault. The tripping of anti-islanding protections may become even more difficult[2].

Therefore, the anti-islanding protections settings must be chosen carefully, as they depend on two different needs:

- small tripping time, small voltage/frequency allowed band, according to the reclosing cycle chosen by each different DNO;
- large tripping time, large voltage/frequency allowed band in order to avoid unwanted tripping.

STUDY CASE

Anti-islanding protection schemes have been introduced at the DG's PCC in order to detect an islanding operation and hence avoid hazardous network scenarios.

Passive anti-islanding protections may not operate in some circumstances of small power mismatch. In addition disturbances non related to islanding can create

2 In presence of inverters (as for PV plants) the different features of internal active anti-islanding protections (no strict standardization is in force) and their mutual influence, make the embedded protective functions completely ineffective, as they work in a non coordinated way [10].

voltage and frequency oscillations that may activate (incorrectly) the relay tripping. This unwanted tripping usually occurs in case of disturbances in the HV network or fault in adjacent feeders of the MV distribution network.

The purpose of the study is to carry out a detailed analysis of a realistic radial structure distribution network with DG connected in order to verify the performance of passive anti-islanding protections in case of short circuit at the distribution level.

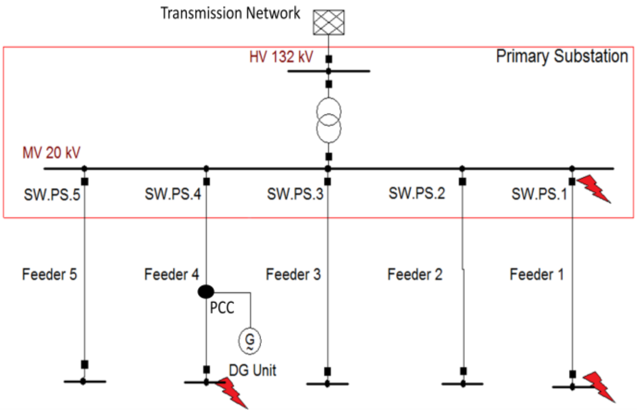

Fig. 2: Distribution network case study

The study has been carried out exploiting the DIgSILENT Power Factory package capability for the simulation of electromechanical transient (RMS models). The study case network is composed by five feeders (Fig. 2) at Vn=20 kV; in Feeder 4 a DG unit (a synchronous machine with rated power of 5 MVA and acceleration time constant of 5 s) is connected to the network though a PCC, containing anti-islanding protections; while all other feeders are passive (i.e. without DG units). Finally, the primary substation is connected to 132 kV transmission system. Load contribution during short circuit simulation can be considered negligible: as a consequence load model is not taken into account. [12]

Behaviour of present anti-islanding protections

Short circuit events in different point of the distribution network (Fig. 2) have been studied in order to focus on the problem of unwanted tripping and to find which passive protection ensures the best performance. A symmetrical fault at the end of Feeder 4 (active feeder) and two symmetrical faults at the Feeder 1, at the end and at the beginning of the feeder, are simulated.

On top of each feeder an overcurrent protection is installed and a time-independent threshold is set at 1 kA with a clearing time of 120 ms.

At PCC voltage and frequency relays, set according to Italian standard (81<:49.7 Hz, 81>: 50.3 Hz, 27: 0.7 p.u. and 59: 1.2 p.u.) are considered.

Furthermore ROCOF relay and vector shift relay are considered. These two protections are set in order to have the same performance of frequency relay (i.e., the same NDZ in terms of power unbalance) in case of islanding operation. [12] Settings that give the same performances of Italian frequency relay are equal to 1.12 Hz\s for ROCOF relay and 2.5° for vector shift relay. [2]

A short circuit is simulated and voltage, frequency, ROCOF and vector shift are analyzed. In particular the event has been assumed at t=0 s. Moreover the simulation has been carried out according to the Italian normalized automatic reclosing time of the CBs installed in the Primary Substation (400 ms).

In case of fault in Feeder 1, i.e. feeder adjacent to the feeder in which DG unit is connected, the anti-islanding protections should not operate; after the Feeder 1 overcurrent relay trip, the system has to achieve a new steady state with DG unit connected. During fault at the beginning of Feeder 1, voltage at PCC (Fig. 3 at left) suddenly decreases and after 120 ms (overcurrent relay trip) it achieves its rated value.

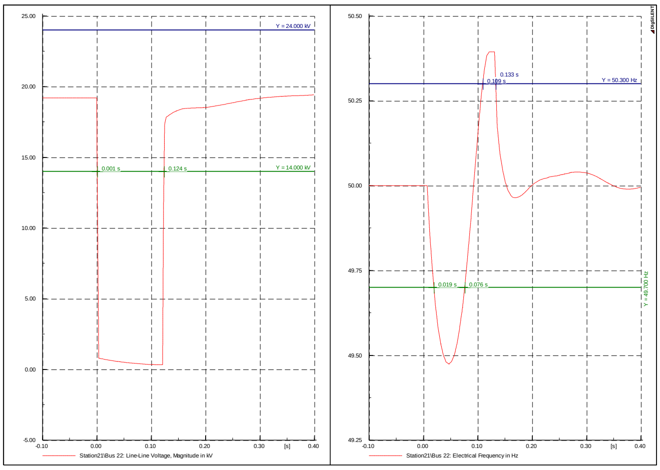

Fig. 3: Voltage and frequency at PCC_ Short circuit at the beginning of Feeder 1

Thanks to the intentional delay, protection 27 doesn't operate. On the other hand frequency oscillations at PCC (Fig. 3 - right) cause DG disconnection.

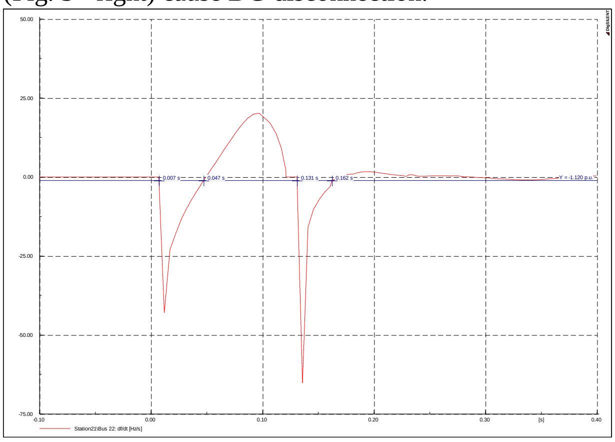

Fig. 4: ROCOF at PCC_ Short circuit at the beginning of Feeder 1

Both ROCOF relay and vector shift thresholds are violated immediately after the fault event (Fig. 4 and Fig. 5): by adopting these protection systems unwanted tripping may often occur.

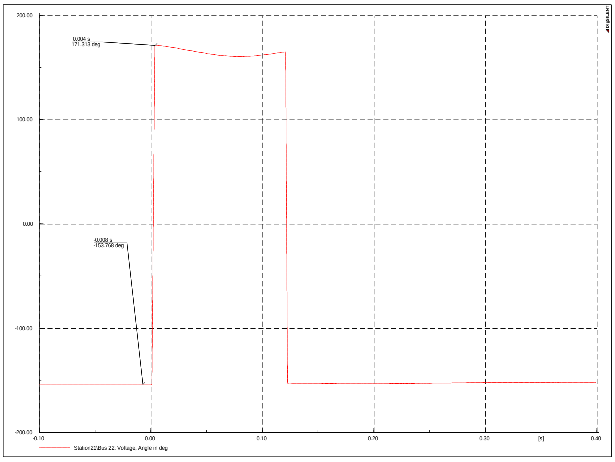

Fig. 5: Vector shift at PCC_ Short circuit at the beginning of Feeder 1

During short circuit at the end of Feeder 1, frequency oscillations don't cause relay operation due to the higher electrical distance between DG power plant at electrical fault. Anyway ROCOF and vector shift relays are quite sensitive to network disturbances and also in this situation, that represents the less critical fault, they could separate DG to the rest of the network. This means that adopting threshold close to nominal values, necessary to guarantee a good reliability for islanding events, unwanted tripping may occur.

In case of short circuit at the end of Feeder 4 (the active feeder) the overcurrent protection operation creates an islanded feeder in which the connected generator sustains fault current. Anti-islanding protections have to separate DG in order to guarantee arc extinction and to ensure good operation of network automation. In fact all four relays analyzed generate tripping signal in a short period of time before automatic reclosure. [12]

Possible improvements in protection strategy

Two solutions have been proposed with the goal to reduce unwanted tripping of passive anti-islanding protections.

- Intentional delay: the adoption of an intentional delay, increasing the protection operating time can reduce the number of nuisance tripping; protection action must be slower than overcurrent protection of adjacent feeder and faster than automatic reclosing time of network automation; this coordination can be tough [5].
- Minimum voltage block: the voltage dip at the PCC is exploited to avoid frequency relay operation. When voltage goes under a threshold V_{min}, the frequency protection is blocked avoiding unwanted tripping in case of short circuit; with a V_{min} set to 0.8 p.u. [8] it is possible to select the less critical fault (i.e. at the end of Feeder 1).

The results achievable by means of an intentional delay can be easily understood by looking at the right side of Figure 3.

As for minimum voltage block strategy, some results are shown in the following Figure 6.

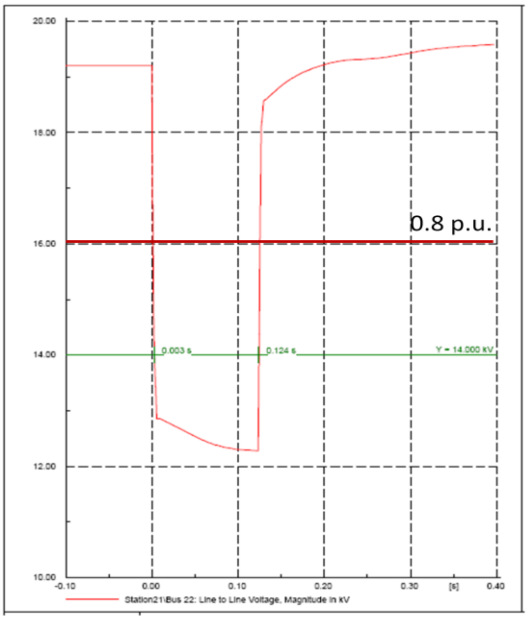

Fig. 6: Voltage at PCC_short circuit at the end of feeder 1

Voltage oscillation at the PCC in case of fault at the end of feeder 1 is shown; it can be seen that, in this case, the voltage goes under 0.8 p.u.; as a consequence, frequency relays can be easily blocked based on this information, in order to avoid an unwanted tripping.

The two proposed interventions can simply improve the interface protection behavior. In Italian Electric Committee (CEI), during the works concerning standards for customers connections to MV and LV distribution networks, other interventions have been considered.

- An increase of fast reclosing time of MV feeder CB, from 400 ms to 600 ms.
- The generation of a communication signal indicating the availability of a communicating channel between primary substation and interface protections.
- The transmission of a proper tripping signal to interface protections, generated in the PS when islanding condition is detected (e.g. due to fault clearing feeder protection tripping or simply operation needs, at MV level and HV level).

The above mentioned proposals will allow to adopt more adequate settings for protection thresholds (frequency in particular) in order to better distinguish between islanding operation and network perturbations [11][13].

CONCLUSION

Passive anti-islanding protections have been studied and discussed in case of faults in different points of the network.
Relays are set in order to detect the same islanding events; in this way it is possible to directly compare the relevant behavior in case of external perturbations.
Voltage relay is able to select short circuits: in most cases, an intentional delay (200 ms) allows to avoid a large part of unwanted tripping. On the other hand, frequency relay is sensitive to short circuits: faults close to MV busbar may cause unwanted tripping, whereas in case of electrical faults far enough from PCC the relay is not triggered, depending on the distance from the fault and on the short circuit power of the network.
On the contrary, unwanted tripping are common in electrical systems with ROCOF relay and vector shift relays; indeed, they are able to detect small frequency deviations due to faults far from the PCC.
The solutions simulated in the paper allow to avoid unwanted tripping when standard relays based on frequency measurements are applied.
Nonetheless, the coordination of passive methods requires a trade-off between reliability and selection of events: only the transmission of proper intertrip signals will allow overcoming the present issues of interface protection operation in presence of huge amounts of DG on distribution networks.

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