CONDITIONS FOR INCREASING DER ANTI-ISLANDING PROTECTION FREQUENCY RANGE

Miguel VERÍSSIMO
EDP Distribuição – Portugal
miguel.verissimo@edp.pt

André NEVES
EDP Distribuição – Portugal
andre.neves@edp.pt

Miguel LOURO
EDP Distribuição – Portugal
miguel.louro@edp.pt

Nuno LOPES FILIPE
EDP Labelec – Portugal
nuno.lopesfilipe@edp.pt

Andreia LEIRIA
EDP Labelec – Portugal
andreia.leiria@edp.pt

Luís Marcelino FERREIRA
Ambertree - Portugal
marcelino.ferreira@ambertree.pt

Pedro CARVALHO
Ambertree - Portugal
pedro.carvalho@ambertree.pt

Fernando CARVALHO
Ambertree - Portugal
fernando.carvalho@ambertree.pt

Tiago SANTOS
Ambertree - Portugal
tiago.santos@ambertree.pt

ABSTRACT

The changing of the traditional generation profile from TSO connected to DSO connected can have the potential to amplify system frequency events if due care is not taken.

Commission Regulation (EU) no. 2016/631 established a wider frequency range that Distributed Generation (DG) modules need to comply with, being the driver for increasing the DER contribution to grid stability and security in case of system disturbances. However, those changes may increase the chance of unwanted islanding in the distribution network. Islanding, by itself, does not constitute a situation that needs to be totally prevented. When planned, or controlled, it may be a useful mode of operation in some cases.

Currently, frequency protections at the DG level, among other functions, are used by the DSO not only to respond to a systemic event, but also to eliminate unwanted islanded systems. Extending frequency parameters may not be a reliable solution for both systemic and local events. Especially in the presence under-frequency load shedding schemes which will tend to adapt the load to the generation in the network. Hence, other ways for unwanted islanding detection may be required.

An extensive study on islanding formation was carried out considering both real and simulated scenarios based on two sections of EDPD's grid connected to different types of generation. It was found that unwanted islanding may occur even without active frequency control generation.

Considering the results, this paper will also present the strategy envisioned for the Portuguese grid aiming to contribute to an European synchronous system resilience using additional communication-based anti-islanding detection methods.

INTRODUCTION

The continuous growth of Distributed Energy Resources (DER) connected to European electrical grids and the increased relevance of the installed power when compared with more traditional energy sources, provided the basis for Commission Regulation (EU) no. 2016/631 that establishes a network code on requirements for grid connection of generators [1]. Among other requisites, this network code specifies a wider frequency range, 47.5Hz – 51.5Hz, that Distributed Generation (DG) modules shall be able of operating without disconnecting from the grid, increasing its contribution to grid stability and security, particularly in case of system disturbances and emergency recovery plans.

In the Portuguese case, the practice since the 1980s is the use of under/over-frequency protection at DG-grid connected facilities for unwanted islanding elimination. This position was reflected in the Portuguese Technical Guide for DG connection to the grid, dated 1989 [2]. Currently, many of DG facilities, especially those located at Medium Voltage (MV) network, are equipped with a frequency protection in the range of 49.5Hz – 50.5Hz. A wider range of frequency protection, 47.5Hz – 51.5Hz, with specific time periods for operation may apply in some cases and in special conditions.

An extensive study was carried out with the main purpose of analyzing if the grid frequency range may be extended in accordance with network codes (which are not applicable to pre-existing DG unless in the case of major refurbishment), without increasing the probability of under-frequency operation, and, at the same time, preventing unintentional islanding formation.

Islanding operation, by itself, does not constitute a situation that needs to be totally prevented. When planned, or controlled, it may be a useful mode of operation in some cases, for instance in the sequence of a major system disturbance, planned works that need to sectionalize the utility system, or even during a step-by-step grid recovery after a blackout.

However, unintentional island mode of operation is an undesirable situation for the Distributed System Operators (DSO), as degradation of power quality and system stability and security issues may arise, like the security of maintenance field teams.

To achieve the purposed goals, a deep benchmarking was firstly conducted on international standards and on

European DSO's best practices and recommendations regarding under/over-frequency protections and anti-islanding detection methods. An extensive study on islanding formation was carried out by analyzing real unwanted islanding events in the Portuguese network and numerous simulations were also conducted using different types of generation and load profiles.

BENCHMARKING

An extensive research was carried out with several documents being analyzed to characterize available islanding detection methods, as well as the international standards and best practices and recommendations that are being employed by EDPD's European counterparts.

Unplanned islanding detection methods are one of the main challenges to Protection Systems. Various anti-islanding algorithms and detection methods have been developed over the years. They can briefly be classified into two families, namely local islanding detection techniques, such as the conventional Under/Over Voltage/Frequency Protection, Rate of Change of Frequency (RoCoF), or Sandia Frequency/Voltage Shift, and remote islanding detection techniques, such as Transfer Trip Schemes or Power Line Carrier Communication (PLCC).

The former methods can be divided into active and passive and rely on the measurement of system parameters at the DG, which raise some drawbacks such as a large non-detected zone (NDZ). Hybrid method evolved from the combination of both active and passive methods, therefore showing higher effectiveness.

Remote islanding detection techniques are based on the communication between the utility grid and the DG. Those techniques are becoming more popular as the they proved to be more accurate (smaller NDZ) and more reliable. However, the need for communication equipment make these methods economically unviable in many cases. Figure 1 summarizes the hierarchy of anti-islanding detection methods [3].

Research on international standards, codes and regulations were carried out and it was found that, although not all countries have requirements for anti-island protection, the need to avoid unplanned islanding formation is consensual, as it can put system stability and people security at risk.

For its part, conventional frequency protection is widely mentioned and used. Frequency ranges and detection time in which DG may operate still vary from country to country. However, EU regulations and ENTSO-E recommendations are forcing countries to adopt a widened range of permissible frequency.

PORTUGUESE LEGISLATION AND PRACTICES

As in other European countries, Portuguese legislation does not specify any requirements for the use of anti-island protections. However, DG facilities are obliged to have protection systems at the grid interconnection point with under/over-frequency and voltages functions.

The Portuguese Technical Guide for DG connected to the grid [2] states that DG facilities must have their protection systems coordinated with the utility protections, so that internal faults are properly isolated assuring selectivity. It also recommends the constitution of a clear interface protection block between the network and the generator, including, under/over frequency and voltage functions, as mentioned before, as well as, zero sequence voltage and current protection functions.

Recently, a new document applied to Production Units for Self-Consumption, [4] established specific rules applicable to PV installations, in addition to the other specifications established in [2]. This document states that all PV installations must have the legally defined protections for interconnection with the distribution grid.

EDPD's Protection and Automation General Guide [5] which defines settings and active functions for its

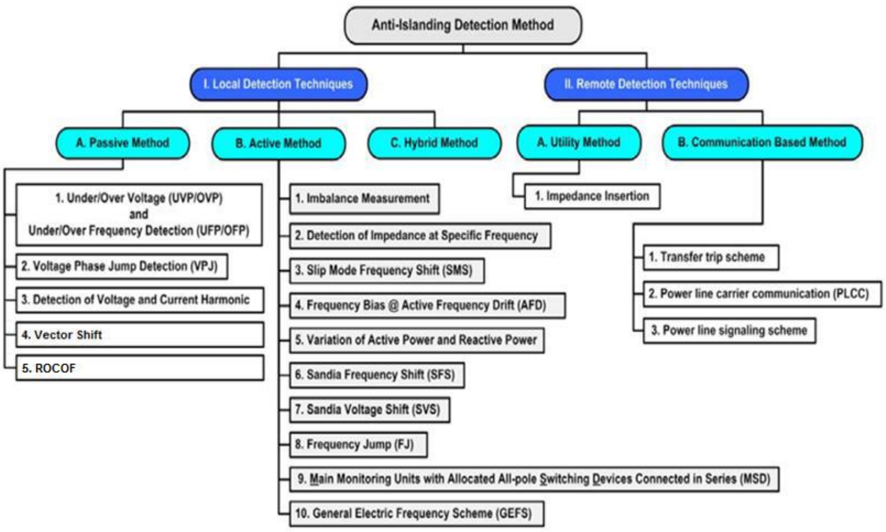

Figure 1 – Overview of anti-islanding detection methods.

protection systems and boundary ones, defines the use of a frequency range of 49.5–50.5Hz for most of the DG connected to the grid. A wider range of frequency protection, between 47.5–51.5Hz, with specific time periods for operation may apply in some cases and in special conditions.

SIMULATION SCENARIOS

To study the probability of island formation in the mainland Portugal Grid, four simulation scenarios were considered based on two sections of EDPD's grid connected to two DG with different technologies and sufficient power generation to supply the local load. In one of the selected grids a real unwanted island formation event has already taken place in the past [6].
Simulations were carried out using AmberTREE's DPlan transient stability analysis. A stable islanding system was considered to occur when the frequency and voltage stabilize over a period not exceeding 47.5-51.5Hz and 0.9-1.1pu, respectively.
The four simulated scenarios were later used to assess the behavior of anti-islanding detection methods that were found to be the most frequently recommended in Europe: RoCoF and Vector Shift. MATLAB was then used to conduct all of the protection function simulations. Those anti-islanding protections were modeled considering the results of previous simulations as inputs and thresholds values of 0.8Hz/s for RoCoF and 10º for Vector Shift were used as recommended in some national network codes. As for operating time settings, standards values were not found. For RoCoF it was considered a delay time of 200ms and a measuring window of 800ms. For Vector Shift, a greater delay time of 300ms was chosen in order prevent unwanted trips.

Islanding with CHP Power Plants

Combined Heat and Power (CHP) power plants connected to EDPD's High Voltage (HV) grid were considered for the first two simulation scenarios. A real unwanted island formation event had already taken place in the past in the selected part of the grid [6]. As shown in Figure 2 it consists in a EDPD HV/MV substation connected to two CHP facilities (synchronous generators with 8.8MVA each) by one HV line.

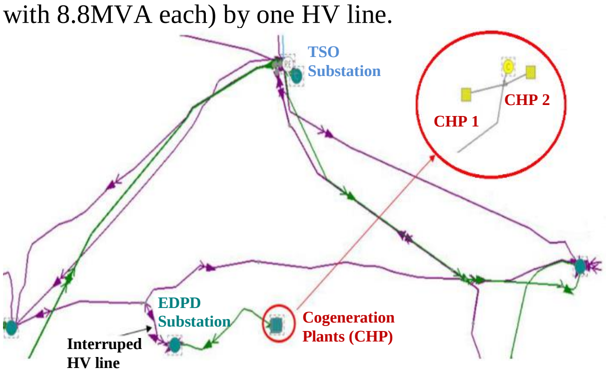

Figure 2 – Section of EDPD's grid considered for the studies.

The substation is connected to the rest of the utility grid by one other HV line. In case of a disturbance in this line an islanding formation is possible.

Case 1: A first simulation scenario with CHP power plants is carried out, considering generators with voltage-frequency regulation capabilities.
The islanding event is preceded by a three-phase fault on the HV line that connects EDPD substation to the rest of the utility grid. The fault caused a voltage dip of 0.3pu during 200ms. After its clearance, the HV line became unavailable. In the pre-fault power flow, generation and load were unbalanced by 0.48 MW and -3.36 MVAr.
Simulation results showed that voltage and frequency stayed within the currently defined range of 0.9pu-1.1pu and 49.5Hz-50.5Hz, respectively. A transient is observed after the fault as the generator controls try to maintain frequency at 50Hz and pre-fault voltage level. All performed simulations demonstrate that islanding formation are enhanced using such controls.

Case 2: The same conditions were replicated in a second simulation scenario with no voltage-frequency control in the power generation facilities.
With a pre-fault power flow mismatch of 0.48 MW and -3.36 MVAr, as in the previous case, the voltage stabilizes below 0.9pu, since the reactive power is no longer compensated by the voltage regulator of the synchronous generators. However, a small change in the load of the islanded system for a mismatch of -0.5 MW and -1 MVAr is enough to get voltage back above the lower limit (Figure 4).

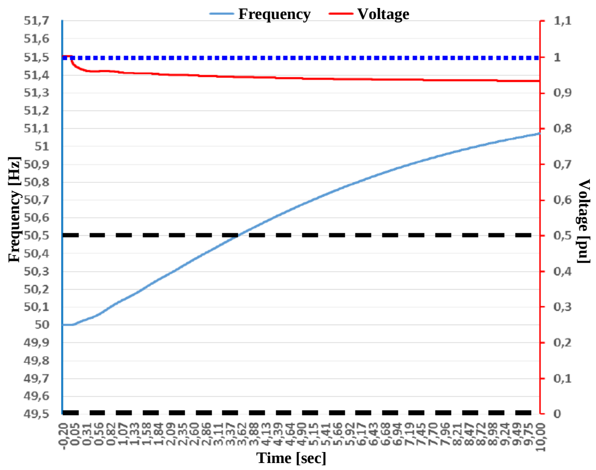

Figure 3 – Frequency and Voltage measured in the CHP1.

Regarding frequency the upper limit of 50.5Hz is exceed after 3s, which would lead to an over-frequency protection trip. Although, considering the new frequency range of 47.5Hz-51.5Hz (EU 2016/631), an islanding operation mode would be stable.

Islanding with Hydro and Wind Power Plants

A third and fourth simulation scenarios were considered with different types of DER generation, namely hydro and wind. A different portion of the utility grid was used, but grid topology remains, as it is composed by two different power stations connected to one EDPD HV/MV Substation (load), which connects to a TSO Substation by a HV line. As in previous cases, a 3-phase fault was simulated in the HV line that links TSO and DSO, and it remain unavailable after the fault clearance. Hence, an islanding operation mode is possible between the two power plants and EDPD substation.

Case 3: A third simulation scenario with two hydro power plants without voltage-frequency capabilities were carried out. In the pre-fault power flow, generation and load were unbalanced by 1 MW.
The results showed that an island system would not be maintained with currently frequency range of 49.5Hz-50.5Hz, but considering a wider range would make it possible.
With no voltage-frequency regulation available, it became clear that there is a relationship between the value of the generator inertia and the maximum value that the frequency reaches. Simulations with different inertial values were performed. It was noted that system inertia is an important variable to islanding formation.

Case 4: For the fourth simulation scenario one hydro power plant and one wind power facility were connected to EDPD's substation.
In the pre-fault power flow, generation and load were unbalanced by -1 MW and 1.1 MVAr. The simulation results are presented in Figure 4.

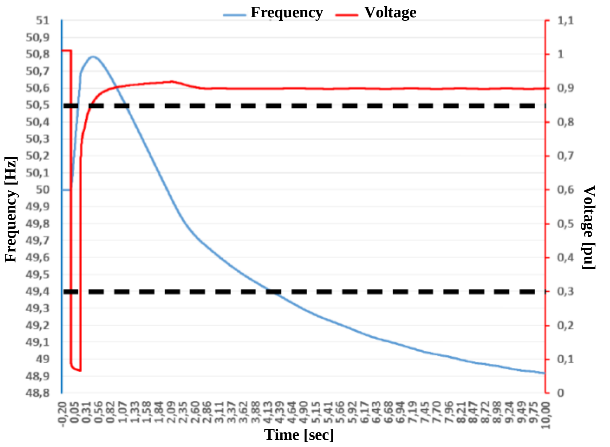

Figure 4 – Frequency and Voltage at the Hydro Plant.

It can be noted that island operating mode would not be maintained with currently frequency range, as in the third scenario simulations. Considering the wider frequency range of 47.5Hz-51.5Hz an island would be created with frequency stabilizing around 48.8Hz after 16sec.
In this simulation scenario it became clear that unwanted islanding formation is possible only when the amount of wind power is relatively low in relation to other forms of generation. However, new requirements imposed on wind power facilities, regarding its contribution to grid stability, could lead to an increase of uncontrolled islands formation in networks with greater penetration of wind power generation.

RoCoF and Vector Shift Simulations

The four simulation scenarios were considered to assess the behavior of RoCoF and Vector Shift anti-islanding detection methods. Table 1 summarizes the results.
The tested anti-islanding protections showed some detection limitations, mainly when there is only a slight unbalance between generation and load and/or when a small disturbance affects the system. In addition, in Cases 3 and 4 a reduction in the measuring window setting was necessary for RoCoF to detect an islanding mode of operation mode. Nevertheless, it should be noted that reducing protection settings would make the system more vulnerable to unwanted trips. RoCoF limitations are discussed in [7]. The absence of an algorithm standard causes RoCoF to have very different performances for the same settings (i.e., it's vendor specific), reducing its reliability.
By its turn, Vector Shift proved to have a greater NDZ when comparing with RoCoF and its performance is easily influenced by delay time setting.

Table 1 - Simulation results for RoCoF and Vector Shift.

Cases	RoCoF	Vector Shift	Notes
1	✓	✓	-
2	✗	✗	No methods were capable of detecting.
3	⚠	✓	RoCoF tripped after settings changes.
4	⚠	✗	RoCoF tripped because wind power makes the islanded system more unstable.

ALTERNATIVE ANTI-ISLANDING METHODS

From both the performed benchmarking and the anti-islanding protection simulations it was possible to conclude that local detection methods present some drawbacks. Two solutions based on innovative operating principles are presented in this section. EDPD have already launched two pilot projects to study both solutions.

PMU-based Islanding Detection Method

A reliable solution would be the use of PMU (Phasor Measurement Unit) units to compare electrical quantities at the DG (Point A) side with the utility substation side (Point B). The units receive a GPS signal, which allows synchronization of data. Communication between all units could be done via optic fiber, radio signal or GPRS/3G/4G, the latter being the best option. In this method, the loss of the grid is detected by the algorithm of a central processing unit, which uses data from both PMU, located in Point A and B. In the event of an island formation, frequency, as well as voltage angles, or even harmonics, in both points will differ and those differences

can be used as a parameter for islanding detection.
Turning back to Cases 2 and 3, simulations show that a PMU-based detection method would be effective. In the newly created islanding system, generation will balance load and a frequency and a voltage angle difference are quickly reached.
In the event of communication failures, DG frequency protection could automatically change to an operating mode with a narrower setting range of 49.8Hz-50.2Hz.
Despite the effectiveness of PMU-based anti-islanding detection method, there are still not many commercial solutions to implement this type of protection, so the associated cost may still be high which makes it economically unviable for DG connected DSO grid.

Transfer Trips Scheme

Considering the associated cost of PMU-based method, another communication-based technique is proposed (Figure 5). This solution would require a router directly connected to the DG protection which would send electrical quantities measurements to the system operator via IEC61850 protocol. The DG-side router could communicate via 3G/4G in a private secured APN with other router in the utility substation. Substation router would centralize all the data from the DG connected to that specific grid and send it up to the SCADA system.
When a disconnection is detected at the substation, a central algorithm can determine which areas have become islanded, and could send an appropriate signal to generators, to either remain in operation, or to trip. SCADA systems can be used for this purpose [8]. Again, in the event of communication failures, DG frequency protection could automatically change to an operating mode with a narrower setting range.

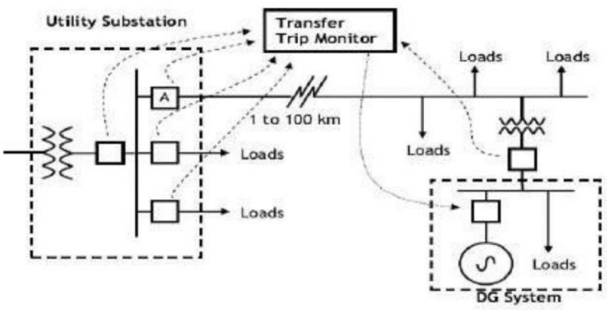

Figure 5 – Transfer trip scheme [8].

CONCLUSIONS

The increasing penetration of DG in the utility grids is bringing new challenges to European DSOs. Requirements for a higher contribution of DER to the stability and security of the system in the event of a system disturbance were established by EU 2016/631.
Portuguese DSO EDPD, EDP Labelec and AmberTREE carried out an extensive study on the necessary conditions to increase the grid frequency operational range while preventing unintentional islanding formation.
To start with, a benchmarking on international standards, best practices and recommendations was performed. We have found that grid codes recommended the use of RoCoF and Vector Shift as anti-islanding detection methods necessary to avoid unplanned and/or uncontrolled islanding grids.
After the benchmarking, an assessment on the necessary conditions for an island formation was conducted considering four simulation scenarios based on two sections of EDPD's grid connected to DG with different technologies. Simulation results proved that extending frequency operation range leads to a potential increase in island formation risks even without active frequency control generation.
Finally, in a second set of simulations, based on the same four scenarios, the reliability of the most used anti-islanding detection methods, RoCoF and Vector Shift, was assessed. Results have shown that both techniques present some limitations, mainly because their algorithms performance are very sensitive to settings. Two other solutions based on innovative operating principles were then presented: PMU-based Islanding Detection Method and Transfer Trips Scheme. These solutions were tested in the worst-case simulation scenario and proved to be more robust solutions alternatives.
In conclusion, our study demonstrated that it is possible to extend the operating frequency up to a range of 47.5-51.5Hz if the use of robust and reliable anti-islanding detection methods is ensured for the grid sections where island formation is probable due to a small imbalance between generation and load.

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