Islanding detection in smart grids

Adrian Timbus, Alexandre Oudalov and Carl N.M. Ho
ABB Switzerland Ltd., Corporate Research
Segelhofstrasse 1K, P.O. Box,
5405 Baden-Dättwil, Switzerland,
Email: adrian.timbus@ch.abb.com,
alexandre.oudalov@ch.abb.com

Abstract—All distributed generators (DG), especially those connected to low voltage distribution grids are required to detect islanding conditions. The methods for detecting islanding are classified in three main categories: passive, active and communication based. Passive methods are based on grid monitoring, are easy to implement but have a large non-detection zone in the case local generation meets the load demand. Active methods, which are commonly used today, may reduce the non-detection zone but in the case of large amount of DGs installed, power quality problems are foreseen. The communication based methods are seldom used today mainly because of high cost of communication.

However, if the islanding detection schemes can use the communication infrastructure to be deployed for smart grids, e.g. for metering, feeder automation, etc. the communication based methods will become cost competitive with the active methods without their weaknesses.

This paper focuses on communication based methods and analyzes the influence of bidirectional power flow on the existing methods. The paper also proposes a new method to be used in a smart grid infrastructure.

Index Terms—islanding detection, smart grid, distributed generation

I. INTRODUCTION

Lately, distributed generation based on renewable energy resources registered an exponential growth facilitated by the policy makers, global concerns about CO₂ emissions, energy shortage, interest in clean energy production, etc. Energy suppliers using power plants based on conventional fuels (coal, gas, etc.) are also investing in the renewable sector such as wind turbines and photovoltaic systems. This leads to a fast and continuous development of technology in this specific area, bringing these systems at a point where their reliability and competence is not anymore discussed. However, for connecting such systems to the utility grid, several conditions have to be met. These conditions are normally published by standardizing institutions such as IEC and IEEE but also by local (country) regulating authorities. A very important requirement which is mandatory to distributed generators is their ability to detect islanding conditions.

Islanding refers to the condition of a distributed generator (DG) continuing to power a part of the grid even though power from electric utility is no longer present. Unintentional islanding can be dangerous to utility workers, who may not realize that the particular part of the network is still powered even though there is no power from the main grid. Also, unintentional and non-controllable islanding can damage customer equipment, especially in situations of re-closing into an island. For that reason, distributed generators must detect islanding and immediately disconnect. The probability of having islanding conditions is very small because, when the grid power is lost, the generated power (both active and reactive) of distributed generators has to match almost perfectly the power consumed by the loads including losses, otherwise the under/over voltage and under/over frequency relays of generators would cease power generation.

Lately there has been a lot of interests in micro-grids, i.e. distribution grids that can operate in controllable, intentional islanding conditions, decoupled from the main grid. In case of such grids, islanding detection is still important in order to switch the control modes of distributed generators from power injection to voltage and frequency control during disconnection and opposite during reconnection to the main grid.

This paper gives an overview of the available methods for detecting islanding, without going to much into technicalities for each individual method. The contribution of the paper is an assessment of smart grid’s influence on islanding detection methods. The overview of existing methods is detailed in Section II followed by a brief description of the requirements from the standardization organizations and local (country level) demands for islanding detection in Section III. Section IV introduces the smart grid concept and assesses some possible changes to islanding detection methodologies given the availability of a communication infrastructure in smart grids.

II. OVERVIEW OF METHODS

Booming of distributed generators industry combined to requirements for islanding detection has led to an intensive research and development of methods for identification of islanding conditions. These methods can be classified in three main categories:

- passive methods
- active methods
- communication based methods

A comprehensive report on methods and their classification has been realized in [1] and [2]. A brief description of the methods and their classification is given below.
A. Passive methods

Passive methods are based on monitoring of grid variables by a dedicated algorithm residing in the control of distributed generator or outside in a dedicated device. Most passive methods are looking for abnormal changes in frequency, voltage or phase angle but also in some particular harmonics or the total harmonic distortion (THD).

If the monitoring algorithm detects large or sudden changes of these variables at the point of connection with the utility grid, the inverter will trip. The most common passive methods are [1]–[3]:

- over/under voltage – monitors whether or not the grid voltage goes out of the limits established by the relevant standards (see Fig. 1)
- over/under frequency – monitors whether or not the grid frequency goes out of the limits imposed by the relevant standards (see Fig. 1)
- monitoring rate of change of frequency (ROCOF) and voltage (ROCOV)
- phase monitoring – monitors fast jumps of grid voltage phase
- voltage harmonic – monitors selective (3rd, 5th, etc.) or total harmonic distortion (THD) of grid voltage [4], [5]

Passive methods are quite effective in majority of situations that may occur in the grid; however their non-detection zone (NDZ) does not cover situations when the power absorbed by the load matches almost perfectly the power generated by DG. In such case, the variations in voltage, frequency or phase angle are lower than specified in the standard because the network remains balanced even though the connection with the main grid has been lost. Therefore, the DG would not trip even though an island has been formed. One can use a combination of passive methods and use multi-criteria decision making. In [6] the islanding detection algorithm uses passive methods including frequency and voltage monitoring and the most widely recognized methods like the Rate of Change of Frequency (ROCOF), Voltage Vector Shift (VVS), and Voltage Unbalance.

However, passive methods are generally considered as insufficient anti-islanding protection [1].

B. Active methods

Active methods appeared as a necessity to minimize the non-detection zone of islanding detection methods in conditions when generation matches load. Normally, active methods inject a small disturbance to the utility grid and based on the grid response decide whether or not an island has formed. Disturbances in terms of shifts from normal values to grid voltage magnitude, frequency or phase angle can be added by the DG and, in case of grid connected situation, these disturbances should be corrected by the grid through the voltage and frequency control. However, if the voltage magnitude, frequency or phase angle follow the shift introduced by the DG, it is most likely that the grid has been disconnected, hence an island has been formed. The most common active methods are using:

- positive feedback inside the DG control – the controller tries to alter grid variables such as frequency, phase or voltage magnitude in order to perform:
  - a frequency jump or phase jump – the DG deliberately alters the frequency or phase of the injected current in order to change the frequency or phase of the voltage. If grid frequency follows the inverter current, an island has formed and the PV inverter should disconnect [1], [7], [8]
  - a frequency bias – similar to above [1]
  - Sandia Frequency Shift – similar to frequency jump but elaborated by Sandia National Laboratories [9]–[11]
  - voltage positive feedback, Sandia Voltage Shift – tries to alter the voltage magnitude at the point of common coupling. If the grid follows the changes generated by the DG, the grid voltage will go out of imposed operating ranges and consequently the inverter would trip [1], [10]–[12]
  - injection of harmonics via DG – non-characteristic harmonics are injected by the DG and the grid response is registered [13], [14]. The method is also called detection of impedance at certain frequency. In [13]–[17] injection of non-characteristic inter-harmonic current is used to derive the grid impedance at that particular frequency. The value of inter-harmonic has to be chosen close to the fundamental grid frequency in order to assume that the identified value of grid impedance can be approximated for fundamental frequency.
  - impedance detection – active method which has been promoted by the requirements in the German standard [18]. In [19]–[21] a current spike is periodically injected at the point of common coupling by a grid tied power converter. Based on the voltage response to this disturbance, the grid impedance value is determined using Fourier transform. The influence of non-linear loads connected close to the point of common coupling (PCC) is also addressed and as a consequence additional signal processing method is necessary in order to obtain accurate results. In [22], the phase angle signal used to generate the reference for current controller is slightly altered to be able to estimate the grid impedance based on grid reaction to the generated current. A high frequency signal (600 Hz) is injected at zero crossing in [23] for determining the value of grid impedance. Active and reactive power oscillations are used in [24]–[26] to identify the value of grid impedance.

Although, active methods give better islanding identification, they also distort the delivered power in order to detect islanding conditions. Disturbances in power grid are not suitable when a significant number of DGs are connected on the same feeder. As discussed in [17], because the injected inter-harmonic generated by the DG is unique in the utility network, this particular method
TABLE I: Comparison of islanding detection methods

<table>
<thead>
<tr>
<th>Method type</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Grid friendly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>- grid friendly</td>
<td>- NDZ larger compared to others</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>- easy and cheap to implement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>- low NDZ</td>
<td>- can create power quality problems</td>
<td>- suitable for a finite number of generators</td>
</tr>
<tr>
<td></td>
<td>- some easy to implement</td>
<td>- can lead to nuisance trip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- some difficult to implement</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- possible interaction between converters in the same grid</td>
<td></td>
</tr>
<tr>
<td>Communication based</td>
<td>- reliable</td>
<td>- expensive to implement</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>- some easy to implement</td>
<td>- need communication infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- theoretically no NDZ</td>
<td>- need involvement of utility</td>
<td></td>
</tr>
</tbody>
</table>

would allow the connection of more than one similar generation units on the same grid because synchronization in respect to the inter-harmonic injection is possible [15], [17]. However, only a finite number of inverters can be connected on the same feeder and this number is directly depending on the standard demands regarding disconnection time and the number of injections necessary to obtain accurate impedance identification. Large penetration level of inverters using active methods not only decreases the quality of power in the grid but also increases the non-detection zone of all active methods as discussed in [1].

C. Communication based methods

Another category of methods for detecting islanding is based on communication between DG and the utility grid. In [1], three main methods using communication are detailed:

- Power line used as carrier for communication between the PV inverter and utility grid [27]–[29]. A continuous signal is transmitted by utility network via the power line. A receiver is necessary to be connected to the DG for detecting the loss of this signal and hence determining islanding conditions.

- Signal produced by disconnect. This method assumes that the utility recloser is equipped with a transmitter which communicates with DG when opens [1]

- SCADA based method uses placement of voltage sensors at the location where DG is connected and integration of those sensors in the SCADA system for monitoring and alarming the PV system to disconnect in case of islanding [1], [30]. With an increasing number of DGs connected to the grid, real time monitoring of voltage for each generator in distribution grid can be a cumbersome process.

Communication based methods necessitate the involvement of utility in implementation of islanding detection schemes, making them less favorite for practical implementation. Because communication adds also costs to both DG and the grid infrastructure, these methods are not commonly used today. Using communication standards such as IEC 61850 [31] and its extensions for distributed generators [32], a SCADA/DMS application can be implemented to communicate to all DGs in a distribution grid and inform them about islanding conditions.

D. Comparison of islanding methods

Table I draws on main features of main categories of islanding methods. Passive methods are the basic protection package of every distributed generator connected to utility grid. As of today, active methods are preferred due to their low non-detection zone. However, one of the main drawbacks which may contribute to a shift from using active methods is their negative contribution to the quality of power in the grid. Future availability of a communication network for the power grid combined with more interest from utilities to monitor the assets in the grid may facilitate a move towards the use of communication based methods for islanding detection.

III. ISLANDING REGULATIONS

Global standardization authorities such as IEC and IEEE are the main divers for standardizing requirements and testing conditions for islanding detection. However, there are also country specific regulations which may differ from both IEC or IEEE approaches and which complicate the development of a general solution for the global market. Japan, Germany, Austria and more recently Spain and Italy are known for applying different requirements for connecting DGs to the utility grid.

A. IEC standards

The IEC 61727 standard [33] defines the characteristics of utility interface for photovoltaic systems. The standard addresses power quality issues (harmonics, flicker), normal voltage and frequency operation range, and safety related matters. Regarding frequency deviations, IEC 61727 suggests that for frequencies outside the range of 1Hz, the PV system should cease energizing the network within 0.2 s. With regard to islanding detection, the only mention of this standard is that the PV system needs to disconnect from utility network within 2 seconds after islanding conditions occurred. IEC 62116 [34] defines the test procedure for islanding prevention measures for PV systems. The test system, as well as testing conditions, is well detailed and the PV system is tested in three cases:

- at maximum output power having the input voltage range set larger than 90%
- at 50–60% of the maximum power of the inverter with the input voltage range of 50% ± 10%
• at 25–33% (or minimum allowed) of maximum power
  with less than 10% input voltage range
All testing steps are described in detail in IEC 62116.

B. IEEE standards

Through IEEE 1547 standard [35], IEEE defines the requirements for connection of distributed resources and utility grid. The specified time for ceasing energy production in case of islanding conditions are the same as defined in IEC standard, i.e. 2 seconds. IEEE 929 [36] defines islanding requirements for PV inverters. The standard describes the procedure for testing the capability of PV inverters to detect islanding situations. An RLC circuit having a quality factor Q=2.5 is used to balance the generated power of PV system. Once the power is balanced, the utility circuit breaker is open and the test is initiated and time to trip is recorded.

C. UL standards

Many PV inverter manufacturers advertise their products as UL certified. The Underwriters Laboratories Inc. (UL) specifies the requirements for inverters, converters, controllers and interconnection system equipment for use with distributed energy resources in the UL 1741 [37] standard. Investigating the standard, it has been found that the part related to islanding detection and operating ranges for voltage and frequency has been superseded from the latest version of the standard (2005) and reference to IEEE 1547 standard [35] is made.

D. German standard

The DIN VDE 0126 standard applied in Germany was one of the most demanding standards for islanding detection. The DIN VDE 0126 imposed the methodology for detecting islanding conditions to impedance measurement. Consequently, all PV systems installed in Germany needed to have an impedance detection algorithm in order to be certified. With the new version of the standard (DIN VDE 0126-1-1) [18], the detection of islanding conditions could be done using one of the following three methods:

- impedance measurement – detection of 1Ω grid impedance jump within 5 seconds
- resonant circuit – detection of balanced islanding conditions (using a resonant circuit with a quality factor Q≥2) within 5 seconds (similar to [36])
- three phase voltage monitoring – passive monitoring of external conductor voltage causes disconnection in the event of voltage or phase failures

E. Spanish standard

The Spanish requirements on the connection of photovoltaic installation onto low voltage network are published in the royal decree 1663/2000 [38]. The protection issues are addressed in Article 11 and over/under voltage/frequency protection only are mentioned. The values of over/under voltage are 1.1 and 0.85 the nominal grid voltage, while ±1 Hz is allowed for frequency variations. There is no specification for islanding detection in this decree.

F. Italian standards

The rules for connecting distributed generators in low voltage grids are published by Italian grid operator ENEL [39] and therefore apply to interconnections to the low voltage grids owned by ENEL and considered best practice for other grids in Italy. Similar to Spain, the requirements from ENEL address over/under frequency/voltage protections and do not mention balanced islanding conditions.

IV. SMART GRIDS AND THEIR INFLUENCE ON ISLANDING

A. What are smart grids?

The electrical power system was built up over more than 100 years. It is now one of the most effective components of the infrastructure on which modern society depends. It delivers electrical energy to industry, commercial and residential consumers, meeting ever-growing demand. Most of today’s generation capacity relies on fossil fuels and contributes significantly to the increase of carbon dioxide in the world’s atmosphere, with negative consequences for the climate and society in general.

To satisfy both the increasing demand for power and the need to reduce carbon dioxide emissions, we need an electric system that can handle these challenges in a sustainable,
TABLE II: Differences between today’s grid and the smart grid.

<table>
<thead>
<tr>
<th>Area</th>
<th>Today’s grid</th>
<th>Smart grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>None or unidirectional</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>Metering</td>
<td>Electromechanical</td>
<td>Digital (enabling real-time pricing and net metering)</td>
</tr>
<tr>
<td>Operation</td>
<td>Manual equipment checks, time based maintenance</td>
<td>Remote monitoring, predictive, event driven maintenance</td>
</tr>
<tr>
<td>Generation</td>
<td>Centralized</td>
<td>Centralized and distributed</td>
</tr>
<tr>
<td>Power flow control</td>
<td>Limited</td>
<td>Comprehensive, automated</td>
</tr>
<tr>
<td>Restoration following disturb</td>
<td>Manual</td>
<td>Self-healing</td>
</tr>
<tr>
<td>System topology</td>
<td>Radial; generally top-down power flow</td>
<td>Meshed; multiple power flow pathways</td>
</tr>
<tr>
<td>Reliability</td>
<td>Prone to failures and cascading</td>
<td>Automated, pro-active protection; prevents outages before they start</td>
</tr>
</tbody>
</table>

reliable and economic way. This network will utilize the same basic electric infrastructure we know today, but will also draw on advanced monitoring, control and communications technology that is presently only beginning to be applied. The result will be a grid that is largely automated, applying greater intelligence to operate, monitor and even heal itself. This smart grid will be more flexible, more reliable and better able to serve the needs of a digital economy.

Table II points out the main differences between today’s grid and the smart grid. The topology area in the table, hints at what is perhaps the most fundamental shift that a fully realized smart grid will require. Todays power systems are designed to support large generation plants that serve faraway consumers via a transmission and distribution system that is essentially one-way. But the grid of the future will necessarily be a two-way system where power generated by a multitude of small, distributed sources in addition to large plants flows across a grid based on a network rather than a hierarchical structure.

B. Smart grid influences on islanding

With regard to islanding detection, the availability of bidirectional communication foreseen in the smart grid infrastructure combined with the power quality issues brought by active methods, especially when a large number of DGs are installed in the grid, will favor the communication based methods for islanding detection. One issue which could hold down the growth of these methods is the conservative behavior of utilities and not adopt a centralized protection scheme in case of islanding.

However, another particular propriety of smart grids, i.e. multiple flow paths could have a negative influence on the communication based methods listed above. This paper provides some insights on how islanding is affected by this.

1) Influence of bidirectional power flow on power line carrier: In this case, a dedicated communication device periodically injects a high frequency signal on the secondary side of the transformer station 1 and 2, in front of switching equipments SE1 and SE2. In case the breakers SE3, SE4 and SE5 are closed and substation 1 (SS1) and SS2 operate in loop configuration, two signals may interfere and cause nuisance tripping of some generators. The two signals can be set with different frequencies but then it has to be ensured that all DGs located on the feeder listen to both frequencies.

2) Influence of bidirectional power flow on signal produced by disconnect: The principle of this method is fairly simple, once a switching equipment (SE) opens, it sends out a trip signal to all generators in the network. Providing the existence of a communication infrastructure between the switch and all generators (radio, GPRS, wired), this could be easily realized for today’s radial distribution networks. However, when multiple paths for power flow exist, the switch needs to send out the trip signal in either direction. This can cause undesired disconnection of generators from a properly working part of the network.

As an example, let us consider the situation illustrated in Fig. 3 where two substations (SS) are interconnected through the switches SE4 and SE5. If SE1 is open and SE2 is closed, the power is supplied from SS2 and the local generators. In case SE5 opens, it should send the trip signal only to generators located in the direction of SE4 and downstream. Unless SE5 communicates with SE1 and SE2 and employs an algorithm for establishing the network topology, it will be very difficult for it to decide to which generators to send the trip signal (towards SE4 or towards SE2?). When having only a few switches involved and a fairly simple network topology, the decision algorithm could be implemented at the switch level, however in case of more complex network topology, computational communication time may become an issue.

As a solution to this, the paper proposes an implementation of the islanding detection algorithm at the substation level. Here, a substation computer (which may have also other functions within a smart grid framework) can monitor the status of the switches along the feeder and the interconnecting lines with the neighboring substations. Also, the substation computer can get the network topology from the upper level e.g. distribution control center and hence can perform the logic for deciding to which DGs shall send the disconnect signal in case of islanding. This method distinguishes itself from the SCADA based method presented in the following section through the fact that is localized to a small part of the network and hence can operate in real time, meeting the requirements for disconnect within 2 seconds imposed by standards.

Another novelty of this method is the fact that anti-islanding groups (AIG) could be defined. In case of radial feeders, these groups shall comprise all the distributed generators located between 2 consecutive switching devices. In case of meshed grid, AIG could be defined between the switches with direct
connection (without the possibility of interrupting between any combination of two switches, e.g. SE1-SE3, SE1-SE4, SE4-SE5). Fig. 3 illustrates the concept of AIG within a distribution grid. The main goal of the AIG is to speed up the processing time to detect islanding and this is due to the fact that distributed generators are structured in groups. Once a part of the feeder is disconnected due to opening of switches, the group of DGs connected to that part of the network (modeled as one AIG) receives the disconnect signal from the substation computer.

3) Influence of bidirectional power flow on SCADA based methods: Along with the drawbacks of SCADA based methods mentioned in [2] another issue of this method is the time necessary to assess islanding. Although it is expected that smart grids will provide bidirectional real-time communication, as of today the pulling rate of data into SCADA system is around 5 to 10 seconds. Even considering a very small processing time for islanding assessment, this is far behind the requested disconnection time imposed by regulations, i.e. 2 seconds. Consequently, in order for this method to become efficient and compliant with the standards, a much higher sampling rate will be necessary. Due to large size of distribution networks, this will stress the need for more space in the SCADA database and faster data processing. Moreover, due to large number of customers of Distribution System Operators, the data sent to SCADA system is generally aggregated at secondary substation level, thus no concrete information exists about a particular customer, DG in this case. This situation may change with the installation of smart meters all over the distribution grid, however this will challenge the communication bandwidth and speed and data storage if all data is stored at control center level. An alternative is to decentralize the functionality of the control center among primary and secondary substations.

V. CONCLUSIONS
This paper addresses the challenges imposed by smart grids to existing islanding detection methods. Since it is envisioned that bidirectional real time communication will be a key enable for smart grids, particular focus is set on the islanding detection methods based on communication. The findings of this paper shows that multi-path power flow imposes the most demanding challenges for such methods. The paper proposes an islanding detection method based on local monitoring of switching devices (per substation level) and use of anti-islanding groups to select the right generators to trip when switching equipment opens.

REFERENCES


[34] ——, Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters, IEC Std. 62 116, 2008.


