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Review of Local and Remote Techniques for Islanding Detection in Distributed Generators

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Abstract. In this paper a revision about different techniques for islanding detection in distributed generators is presented. On one hand, remote techniques, not integrated in the distributed generators, are discussed. On the other hand, local techniques, integrated in the distributed generator, are described. Furthermore, it is discussed how the local techniques are divided into passive techniques, based on exclusively monitoring some electrical parameters, and active techniques, which intentionally introduce disturbances at the output of the inverter, in order to determine if some parameters are affected.

Key words

Islanding Detection, Distributed Generator.

1. Introduction

The condition of "Islanding" in Distributed Generators (DGs) is an electrical phenomenon that occurs when the energy injected to the power grid is interrupted due to various factors and the DGs continue energizing some or the entire load. Thus, the power grid stops controlling this isolated part of the distribution system, which contains both loads and generation. This situation may compromise security, restoration of service and the reliability of the equipment. [1] [2].

In the case of several Distributed Generation Systems connected to a low-voltage power grid, it is possible that the amount of energy generated by the distributed system agrees with the amount of energy consumed by the loads on the grid. Under this situation, there is no energy flow towards the power grid, so that the DGs may continue feeding the loads leading to an "Islanding" condition. In addition, when the islanding condition happens, there is a primary security condition which forces the generator system to disconnect from the de-energized grid without taking into account the connected loads.

The "islanding" effect in inverters may result from a failure detected by the grid and the consequent switch opening, accidental disconnection of the grid because of equipment failure, sudden changes in the distribution systems and loads, intentional disconnection for maintenance services either on the network or in the service, human errors, vandalism or acts of nature.

There are many reasons why islanding should be anticipated in the grid-connected distributed generation systems. The main reasons are safety, liability and maintenance of the quality of the supplied energy.

The main idea to detect the islanding condition is to monitor the output parameters of the inverters making up the DGs and/or other system parameters in order to determine if there have been changes that indicate islanding. Islanding detection techniques can be divided into remote and local ones. The latter techniques can be divided into passive and active ones, as shown in Figure 1 [3]..

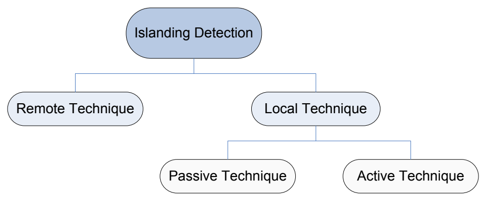

Fig. 1. Islanding detection techniques

Before defining the different methods for islanding detection, it is important to highlight two key features in order to better understand the islanding phenomenon. The first one is associated with the so-called "Non-detection zone" (NDZ), which can be defined as the range (in terms of the difference between the power supplied by the DG inverter and that consumed by the load, in which an islanding detection scheme under test fails to detect this condition [4]. The second feature is associated with the type of loads (potential loads inside an isle), which can be modelled as a parallel RLC circuit. The reason for

using an RLC load is the high difficulty to detect islanding with this kind of loads. Nonlinear loads, such as loads that produce current harmonics, or constant power loads do not present a great difficulty for islanding detection [2].
In particular, RLC loads with a high Q factor pose problems for island detection. The Quality Factor is defined by (1):

$$Q = R \cdot \sqrt{\frac{C}{L}} \qquad (1)$$

This parameter describes the relationship between the stored and the dissipated energy in an RLC circuit.
For these reasons, the islanding detection is an important feature that should be considered when implementing distributed generation systems. In paragraph 2 and 3 of this work the most representative techniques (local and remote) to islanding detection are addressed, indicating their operation scheme, advantages and disadvantages. Finally, some conclusions are presented about the most important aspects covered in this paper.

2. Local islanding detection techniques

These techniques are based on the measurement of some parameters (voltage, current, frequency, among others) on the Distributed Generator (inverter) side. They are classified as passive, based exclusively on the monitoring of these parameters, and active techniques, which intentionally introduce disturbances at the output of the inverter and observe whether the parameters outlined above are affected.

A. Passive Techniques of Islanding Detection

These techniques are based on monitoring of grid voltage parameters such as voltage, current, frequency and/or their characteristics. The inverter energy conversion is interrupted when some parameter falls beyond certain previously established limits.

1) Over/under-voltage and over/under-frequency [5], [6], [7]. Techniques of over/under voltage protection, OVP/UVP and over/under frequency protection, OFP/UFP, allow the detection of islanding phenomenon through the measure of voltage and/or frequency at the Point of Common Coupling (PCC), and subsequent comparison with the limits set for proper operation [9]. If the measured values are outside the established range, the inverter is stopped or disconnected.Figure 2 shows the power balance of the system.

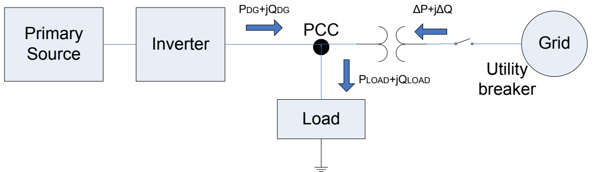

Fig. 2. Power balance of the system.

Equations (2) and (3) describe the power balance of the system.

$$P_{LOAD} = P_{DG} + \Delta P \qquad (2)$$

$$Q_{LOAD} = Q_{DG} + \Delta Q \qquad (3)$$

The behaviour of the system when the grid is disconnected depends on the previous values of ΔP y ΔQ. It is worth to point out that the active power is directly proportional to the voltage. Therefore, if $\Delta P \neq 0$, the amplitude of the voltage will change.

$$V' = \sqrt{\frac{P_{DG}}{P_{LOAD}}} \cdot V \qquad (4)$$

In the case of $P_{DG} > P_{LOAD}$, the voltage increases, otherwise it decreases, which might indicate whether the islanding conditions appears.
Reactive power is a function of frequency and voltage width, so if $\Delta Q \neq 0$, the phase of the load voltage will present a sudden change and the control system will modify the signal frequency of the output current inverter to achieve $\Delta Q = 0$ (i.e. until it reaches the resonance frequency of the load). This change in the frequency may be detected to determine Islanding condition. The equation of reactive power in terms of frequency and voltage is presented by (5).

$$Q'_{LOAD} = Q_{DG} = \left(\frac{1}{\omega' L} - \omega' C \right) V' \qquad (5)$$

The methods outlined above present the advantage of being low-cost solutions but they have a large NDZ. Moreover, these methods are incapable of detecting the islanding condition when the power supplied by the DG matches the power consumed by the loads.

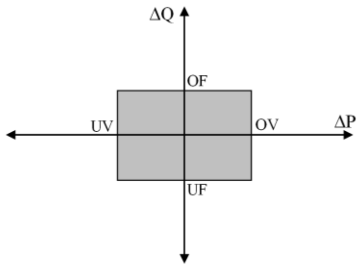

Fig.3. Non-detection zone of OUV y OUF

2) Phase Jump Detection [6], [11]. Phase Jump Detection technique (PJD), involves monitoring of sudden “jumps” of the inverter voltage as a consequence of differences between the voltage inverter and its output current.
During normal operation the current of the inverter is synchronized with the voltage of the power grid through a Phase Locked Loop (PLL).
Figure 4 shows the evolution of the voltage when it is disconnected from the power grid. This phenomenon occurs because only the output current is controlled by the inverter, so that the PCC voltage may be out of phase with regard the current in the case of islanding.
The biggest advantage presented by PJD is its ease of implementation. As the inverter uses a PLL to synchronize with the grid, all that it is needed is the inverter capacity to be disconnected if the phase error between output current and voltage exceeds certain threshold. However, difficulty comes in the implementation of the threshold selection because the phase can be affected by the handling of certain loads such as motors or simply by being on presence of loads that can not produce phase error, which could induce an error in the detection of islanding.

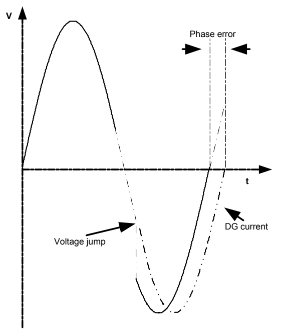

Fig. 4. Operation of the PJD.

3) Detection of voltage and current harmonics [6], [8], [12]. This technique is based on the measurement of the voltage Total Harmonic Distortion (THD_v) at the PCC, the comparison of the measured value with a certain threshold and the inverter disconnection in case of this threshold is exceeded. During normal operation, the voltage at the PCC is the grid voltage, so distortion can be considered as negligible ($THD_v \approx 0$) in most cases. However, when islanding condition happens, the current harmonics produced by the inverter are transmitted to the load, which usually presents higher impedance than the grid. The interaction of the harmonic currents and the grid impedance generates voltage harmonics which can be measured. Therefore, the THD_v variations beyond a certain threshold can be used to detect islanding..

This method has the advantage that its effectiveness does not change where there are multiple inverters. However, it is sensitive to grid perturbations, which makes the threshold establishment more difficult for islanding detection. For instance, with non-linear loads, the voltage distortion at the PCC can be so high that a fault may be erroneously detected even if the grid is present. Additionally, with linear loads the THD_v variation may be too low to be detected.

4) Detection based on state estimators [9].

The basic idea of this technique is based on applying a voltage oriented control combined with the use of resonant controllers. An algorithm based on Kalman filters is used to estimate the third and the fifth harmonic of the grid voltages. The correspondence between the energy of both the estimated values and the measured ones can be used to identify islanding condition.

Detection based on state estimators has the advantage of being a passive method which does not affect the system power quality. It presents a very low NDZ and an islanding detection rate very high, comfortably in line with IEEE. However, it demands more complexity from the programming point of view compared with other passive techniques of islanding detection.

B. Active Techniques for Islanding Detection

These techniques intentionally introduce disturbances at the output of the inverter to determine if they affect grid voltage, frequency and impedance parameters. In that case it is assumed that the grid has been disconnected and the inverter becomes isolated from the load.

Active techniques have the advantage of remarkably reducing or even eliminating the NDZ. However, they may deteriorate the quality of the grid voltages even causing instability.

1) Impedance measurement [14], [15], [16]. Techniques based on impedance measurement seek to detect impedance changes at the output of the inverter, which is produced when the electric distribution grid, which is supposed to have low impedance, disconnects from the system.

The inverter of the DG behaves as a current source which injects a current as follows.

$$i_{DG-inv} = I_{DG-inv} \sin(\omega_{DG} t + \phi_{DG}) \tag{6}$$

Usually, a disturbance is added to the inverter output current, $I_{DG\text{-}inv}$, which causes the output voltage to suffer from changes when the grid is disconnected. This variation is monitored by calculating the *dv/di*, which represents the grid impedance that it is 'seen' by the inverter.

The main advantage of the impedance measurement method is its small NDZ. However, this method has many weaknesses. The first one is that its effectiveness decreases as the number of inverters connected to the grid increases unless all the inverters use this method and they all are synchronized. The second one is that it is necessary to establish an impedance threshold to identify when the grid is connected. This requires the exact value of the grid impedance which is a parameter initially unknown. It makes this method sometimes impractical.

2) Harmonic injection/detection of impedance [14], [17]. This method involves intentionally injecting a specific current harmonic at the PCC. When the grid is connected, if the grid impedance is lower than the load impedance at the harmonic frequency, then the injected harmonic current will flow into the grid.

The size of the disturbance that appears at the voltage amplitude will depend on the nominal values of the grid impedance.

After the grid disconnection, the harmonic current will flow through the load, producing a specific harmonic voltage. The name of this method comes from the fact that the amplitude of the generated voltage harmonics will be proportional to the impedance of the load at the frequency of the injected harmonic current.

This method presents the same advantages and disadvantages of the harmonic detection technique. However, the disadvantages can be overcome if subharmonic signals are injected instead of high order harmonics. Unfortunately, problems are not definitively solved unless the amplitude of the injected harmonics is very small.

3) Slip-mode Frequency Shift (SMS) o Active Phase Shift (APS) [14], [18], [19].

The operation principle of the SMS method is based on varying the inverter output frequency by controlling the phase of the inverter current. Usually, DG operates with unity power factor, so in normal operation the inverter output current-voltage phase angle of the inverter, instead to be controlled to be zero, is made to be a function of the frequency of the PCC voltage, as shown in Figure 5.

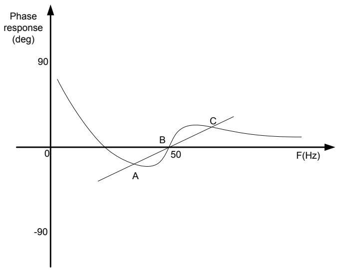

Fig. 5. Phase Angle vs. Frequency.

This method is relatively easy to implement because it is just a slight modification of a component which is already required, the PLL. Additionally, it has a small NDZ compared with other methods. It also has the advantage of being effective when dealing with multiple inverters and it offers a good compromise between islanding detection, the output power quality and transitory response. However, SMS method requires a decrease in the power quality of the DG inverter.

4) Active Frequency Drift (AFD) [14], [18], [19].

The basis of AFD method is to vary the frequency of the output current by means of a positive feedback (Report IEA-T5-09, 2002), (Sun et al., 2004), (Lopes & Sun, 2006). The method is based on the injection of a current into the PCC slightly distorted in frequency as shown in Figure 6. When a grid disconnection occurs, a phase error appears between the inverter current and the voltage at the PCC. The inverter detects this error and tries to compensate it by increasing the frequency of the generated current. This process continues until the frequency exceeds the limits and is detected by the OFP / UFP.

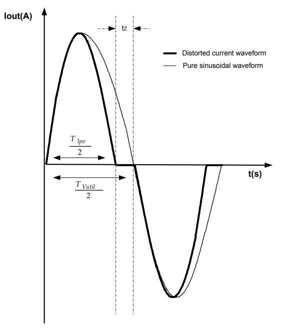

Fig. 6. Example of current waveform distortion

The relationship between t_Z in Figure 9 and half of the voltage period is called the chopping factor:

$$cf = \frac{2 \cdot t_Z}{T_{Vutil}} \qquad (7)$$

This method can be easily implemented and applied to multiple inverters. However, the AFD method produces a small degradation in the quality of the DG output and the inverter has an NDZ that depends on the value of the chopping factor. There are similar techniques allowing to obtain better results by changing the chopping factor, with a significant reduction in the NDZ, like the following ones: Active Frequency Drift with Positive Feedback (AFDPF) [20], AFD with Pulsation of Chopping Fraction (AFDPCF) [21], among others.

5) Frequency Jump [10], [18].

The Frequency Jump (FJ) method is a modification of AFD, and it is conceptually similar to the impedance estimation techniques. In the FJ method, dead zones are inserted into some cycles of the output current waveform. Instead, the frequency is "dithered" according to a pre-assigned pattern.

When the inverter is connected to the utility, the waveform of the voltage in the PCC is imposed by the grid. However, when the grid is disconnected, the Islanding situation is detected by forcing a deviation in frequency. The main advantage of this method is that if the pattern is sufficiently sophisticated, FJ may be relatively effective in Islanding detection when used with a single inverter. Furthermore, this method hardly presents NDZ in single-inverter case and it loses effectiveness when connecting multiple inverters, unless the frequencies dithering between inverters are synchronized.

6) Sandia Frequency Shift (SFS) [14], [18], [23].

This is an accelerated version of AFD and it is one of the positive feedback methods used to prevent the islanding operation. With the grid connected, the method detects and tries to amplify small changes in frequency, but the presence of the grid avoid it. When the grid is disconnected, the frequency changes produce phase error and the positive feedback, in an iterative process, come the frequency beyond the threshold of OFP or UFP.

When the method is implemented, it is calculated the reference frequency for the inverter as a function of both the value at the iteration n and its variation Δf, following (7):

$$f_{inv,n+} = \quad + \quad \Delta \qquad (7)$$

Where f_{n+1} is the reference frequency for the inverter in the $n+1$ cycle, f_n is the frequency in the n cycle and K_f is a constant that allows to accelerate the islanding detection. Finally Δf_n is the frequency variation in each cycle. K_f is designed to compensate the natural tendency of the system to move to the load resonance frequency when such a resonance frequency falls within the thresholds established to detect islanding.

7) Sandia Voltaje Shift (SVS) [14], [24].

This method uses a positive feedback loop of the PCC voltage amplitude and it is similar to the active power variation technique. If the voltage amplitude (usually measured in RMS value) decreases, the inverter reduces its output current and thus the output power.

The response time of the algorithm can be adjusted by a factor *Kv* that increases or decreases the inverter current proportionally to the voltage variation. This value should be chosen following the same considerations that it was described in the active power variation method. Finally, the method leads the voltage amplitude beyond the OVP/UVP limits allowing the islanding detection. To avoid any potential damage of the connected equipment, it is preferable to decrease the voltage amplitude instead increasing it.

SVS is easy to be implemented, and it is considered very effective among the methods that use positive feedback. Normally SVS & SFS are simultaneously implemented, improving the effectiveness of the method.

However, the SVS method has two disadvantages. On one hand it produces a small reduction in the power quality because the PCC voltage is continuously perturbed. On the other hand, efficiency of the MPPT algorithms may be affected.

8) Mains Monitoring Units with Allocated All-pole Switching Devices Connected in Series (MSD), [6].

This method relies on detection of the grid impedance. It uses two monitoring devices in parallel, connected to two series connected switch devices, which are independently controlled. Each one of the units is continuously monitoring the voltage, the frequency and the impedance of the grid.

The advantages of this method are: small NDZ (very effective), redundancy monitoring and regular self-evaluation. However, the method has a high probability of interference with other devices including the grid itself.

9) Variation of active power and reactive power [10], [25], [26], [27].

This method is based on the ability of the inverter to generate independently both active and reactive power. In islanding, the voltage variation with regard to the active power injected by the inverter may be obtained from the power flow. The power supplied by the inverter can be expressed as:

$$V = \quad \cdot \tag{8}$$

It is possible to vary the active power injected by the inverter in order to bring the amplitude of the voltage outside the normal operating range and be able to detect islanding.

Similarly to the relationship between voltage and active power, a strong dependence between frequency and reactive power exists, which may be used to develop another method of islanding, based on measuring the grid frequency.

The disadvantage of this method is that it can generate false detections of islanding when several inverters are connected to the same point of the grid. Moreover, instability problems may appear because the inverter is continuously injecting disturbances into the grid.

10) General Electric Frequency Schemes – GEFS. [26], [28], [29].

This method injects a current disturbance into the system and evaluates the effects on the PCC. The disturbance is added to the control signals in a Synchronous Reference Frame (SRF), usually known as DQ frame. The active power is proportional to the D axis component and the reactive power is proportional to the Q axis component.

This method is easy to be implemented and it has a reduced NDZ. In addition, it has a low impact on the power quality and it is very robust against grid disturbances. Nevertheless, the injection of disturbance signals (frequency and voltage) requires be as small as possible.

3. Remotes techniques of islanding detection

These detection techniques are based on some kind of communication between the grid and the DG. They are more reliable than the local techniques, but they are more expensive to implement. Here are some of these techniques.

A. Impedance Insertion [4], [30].

This method involves the insertion of a low impedance load, usually a bank of capacitors, which is connected to the PCC when the utility breaker opens. As a result, the power balance between generation and load is modified. This disturbance causes a phase change and a sudden variation of the resonance frequency that can be detected by the OUF limits. A certain delay before connecting the additional impedance is mandatory to properly detect the frequency deviation. A scheme of the method is presented in Figure 7.

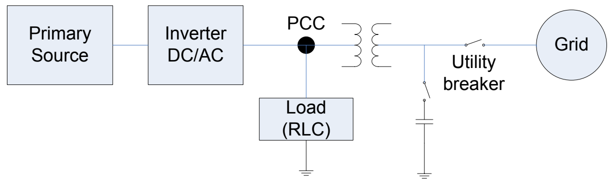

Fig. 7. Scheme of a method based on insertion impedance.

This method has a low response time. In addition, the banks of capacitors can be used also for reactive compensation.

However, it is expensive to implement and the time needed to insert the capacitor bank after the grid disconnection could not meet certain standards. For this reason, the impedance value should be sized according to the minimum variation of phase (and therefore the frequency) that can be detected.

B. Power Line Carrier Communications [6], [31], [32].

This method is a technique that relies on the use of the power line as a communication channel. The basic idea is to transmit a continuous low-energy signal between the transmitter (T) located on the side of the grid and receiver (R) located on the side of the DG. When this communication is disrupted, the receiver send a stopping signal to the inverter and/or a switch (included in the receiver) should be opened in order to isolate the load from the DG. The scheme of this method is shown in Figure 8.

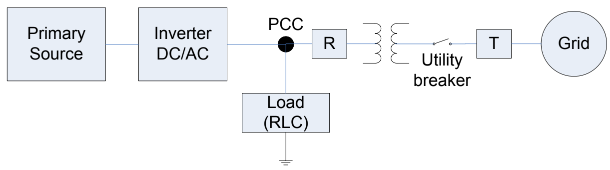

Fig. 8. PLCC system with transmitter (T) and receiver (R).

Among others, the advantages of the method are: Ability to operate in areas with high density of DG. It does not have an NDZ. The inverter output power quality is not degraded. Its transient response depending on the type of signal to transmit, it is possible to use only one transmitter to cover a part of the grid.

Some of the weaknesses of this method are: the cost of the receiver and transmitter can be too high. Moreover certain charges under certain conditions highly abnormal, might replicate the emitted signal by the PLCC which would result in non-Islanding detection.

C. Signal Produced by Disconnect [6].

This method is similar to the PLCC-based method. The SPD method is based on communication between the network and the inverters to avoid Islanding. SPD differs from the PLCC-based method in the type of transmission used (microwave link, telephone link or others). In this way the state of the switch is continuously known by the inverter.

From the point of view of energy management, this method has the advantage of additional supervision and control of both the DG and the grid. Unfortunately, this method presents the great disadvantage of its high cost, which increases with every DG connected to the network. Besides, when the communication is via telephone, the communication wiring should be increased and communication protocols should be set up. This problem can be solved with the use of radio-frequency communications, but to cover up huge distances repeaters are needed, whereas a range of working frequencies should be established which might require licensing.

D. Supervisory Control and Data Acquisition (SCADA) [6], [34].

The inclusion of inverters in a SCADA system is a logical choice for Islanding prevention. SCADA systems use a wide communications network and sensors to control and monitor the grid connected equipment, allowing a fast response to contingencies that may arise in the grid, easing Islanding detection. When the grid is disconnected, a series of alarms are activated for disconnection of the DGs. This method is highly effective to detect islanding, eliminating the NDZ. However, this method presents the disadvantage of being too expensive and requiring a large number of sensors and additional features. Furthermore, it is not feasible in small installations.

4. Conclusión

In this paper several techniques for Islanding detection have been presented. These techniques can be classified into two groups depending on their location in the DG system: remote and local techniques. In the first group the detection algorithm is located at the grid side, whereas in the second group the detection method is located at the inverter side. Additionally, the local techniques can be divided into passive ones, which are based on parameter measurement, and active ones, which generate disturbances at the inverter output. Finally, the advantages and disadvantages about these methods are mentioned.

References

[1] Dincer, Renewable energy and sustainable development: a crucial review, Renewable and Sustainable Energy Reviews, Volume 4, Issue 2, June 2000, Pages 157-175

[2] Martínez, P, Díaz de Basurto, I. Martínez, P. Ruiz, European Union's renewable energy sources and energy efficiency policy review: The Spanish perspective, Renewable and Sustainable Energy Reviews, Volume 13, Issue 1, January 2009, Pages 100-114 I.

[3] Jiayi, J. Chuanwen, X. Rong, A review on distributed energy resources and MicroGrid, Renewable and Sustainable Energy Reviews, Volume 12, Issue 9, December 2008, Pages 2472-2483.H.

[4] M. Pietzsch, Convertidores CC/CA para la conexión directa a red de sistemas fotovoltaicos: comparación entre topologías de 2 y 3 niveles, Bachelor thesis, U.P.C, December 2004.

[5] A.E. Mohamed, Z, Zhengming, Grid-connected photovoltaic power systems: Technical and potential problems—A review Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 112-129

[6] V. Task, Evaluation of islanding detection methods for photovoltaic utility-interactive power systems, Tech. Rep. IEAPVPS T5-09:2002, March 2002.

[7] P. Mahat,; Zhe Chen; Bak-Jensen, B., Review of islanding detection methods for distributed generation, Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DRPT 2008. Third International Conference on, vol., no., pp.2743-2748, 6-9 April 2008.

[8] F. De Mango, M. Liserre, A.D. Aquila, A. Pigazo, Overview of Anti-Islanding Algorithms for PV Systems. Part I: Passive Methods, Power Electronics and Motion Control Conference, 2006. EPE-PEMC 2006. 12th International, vol., no., pp.1878-1883, Aug. 30 2006-Sept. 1 2006.

[9] IEEE 929, IEEE recommended practice for grid interface of photovoltaic (PV) systems. New York, NY: Institute of Electrical and Electronics Engineers, April 2000.

[10] C. Jeraputra, P.N. Enjeti, Development of a robust anti-islanding algorithm for grid interconnection of distributed fuel cell powered generation, IEEE transactions on power electronics, vol.19, no.5, pp. 1163 -1170, September 2004.

[11] H. Kobayashi, K. Takigawa, E. Hashimoto, Method for Preventing Islanding Phenomenon on Utility Grid with a Number of Small Scale PV Systems, Proceedings of the 21st IEEE Photovoltaic Specialists Conference (1991), p. 695-700.

[12] S. Jang, K. Kim, An islanding detection method for distributed generations using voltage unbalance and total harmonic distortion of current, IEEE transactions on power delivery, vol. 19, no. 2, pp. 745-752, April 2004.

[13] M. Liserre, A. Pigazo, A. Dell'Aquila, V.M. Moreno, An Anti-Islanding Method for Single-Phase Inverters Based on a Grid Voltage Sensorless Control, Industrial Electronics, IEEE Transactions on, vol.53, no.5, pp.1418-1426, Oct. 2006.

[14] M. Ropp, W. Bower, Evaluation of islanding detection methods for photovoltaic utility interactive power systems, International Energy Agency Implementing agreement on Photovoltaic Power Systems, Tech. Rep. IEA PVPS T5-09, March 2002.

[15] M. Ciobotaru, R. Teodorescu, P. Rodriguez, A. Timbus, F. Blaabjerg, Online grid impedance estimation for single-phase grid-connected systems using PQ variations, Power Electronics Specialists Conference, 2007. PESC 2007. IEEE , vol., no., pp.2306-2312, 17-21 June 2007.

[16] M. Ropp, J. Ginn, J. Stevens, W. Bower, S. Gonzalez, Simulation and Experimental Study of the Impedance Detection Anti-Islanding Method in the Single-Inverter Case, Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference on , vol.2, no., pp.2379-2382, May 2006.

[17] Z. Chunjiang, L. Wei, S. Guocheng, W. Weiyang, A Novel Active Islanding Detection Method of Grid-connected Photovoltaic Inverters Based on Current-Disturbing, Power Electronics and Motion Control Conference, 2006. IPEMC'06. CES/IEEE 5th International, Volume 3, pages:1 – 4, Aug. 2006.

[18] L.A.C. Lopes, H. Sun, Performance assessment of active frequency drifting islanding detection methods, Energy

Conversion, IEEE Transactions on, Volume 21, Issue 1, pages: 171 – 180, March 2006.
[19] H. Sun; L.A.C. Lopes, Z. Luo, Analysis and comparison of islanding detection methods using a new load parameter space, Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE, Volume 2, pages: 1172 – 1177, 2-6 Nov. 2004.
[20] Y. Jung, J. Choi, B. Yu, J. So, G. Yu, A Novel Active Frequency Drift Method of Islanding Prevention for the grid-connected Photovoltaic Inverter, Power Electronics Specialists Conference, 2005. PESC '05. IEEE 36th, pages: 1915 – 1921, 2005.
[21] F. Liu, Y. Kang, S. Duan, , Analysis and optimization of active frequency drift islanding detection method, Applied Power Electronics Conference, APEC 2007 – Twenty Second Annual IEEE, pages: 1379 – 1384, Feb. 25, 2007-March 1, 2007.
[22] V. Menon, M.H. Nehrir, , A Hybrid Islanding Detection Technique Using Voltage Unbalance and Frequency Set Point, Power Systems, IEEE Transactions on, Volume 22, Issue 1, pages: 442 – 448, Feb. 2007.
[23] X. Wang, W. Freitas, W. Xu, V. Dinavahi, Impact of DG Interface Controls on the Sandia Frequency Shift Antiislanding Method, Energy Conversion, IEEE Transaction on, Volume 22, Issue 3, pages: 792 – 794, Sept. 2007.
[24] V. John, Zhihong Ye, A. Kolwalkar, Investigation of anti-islanding protection of power converter based distributed generators using frequency domain analysis, Power Electronics, IEEE Transactions on, Volume 19, Issue 5, pages: 1177 – 1183, Sept. 2004.
[25] F. De Mango, M. Liserre, A.D. Aquila, Overview of Anti-Islanding Algorithms for PV Systems. Part II: ActiveMethods, Power Electronics and Motion Control Conference, 2006. EPE-PEMC 2006. 12th International, vol., no., pp.1884-1889, Aug. 30 2006-Sept. 1 2006.
[26] Z. Ye, L. Li, L. Garces, C. Wang, R. Zhang, M. Dame, R. Walling, N. Miller, A new family of active antiislanding schemes based on DQ implementation for grid-connected inverters Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual, vol.1, no., pp. 235-241 Vol.1, 20-25 June 2004.
[27] J.B. Jeong, Hee Jun Kim; Soo Hyun Back; Kang Soon Ahn, An improved method for anti-islanding by reactive power control, Electrical Machines and Systems, 2005. ICEMS 2005. Proceedings of the Eighth International Conference on, vol.2, no., pp.965-970 Vol. 2, 29-29 Sept. 2005.
[28] H. Sun, L.A.C. Lopes, Zhixiang Luo, Analysis and comparison of islanding detection methods using a new load parameter space, Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE, Volume 2, pages: 1172 – 1177, 2-6 Nov. 2004.
[29] Z. Ye, A. Kolwalkar, Y. Zhang, P. Du; R. Walling, Evaluation of anti-islanding schemes based on nondetection zone concept, Power Electronics, IEEE Transactions on, Volume 19, Issue 5, pages: 1171 – 1176, Sept. 2004.
[30] K. Hotta, A. Kitamura, M. Okamoto, K. Takigawa, H. Kobayashi, Y. Ariga, "Islanding prevention measures: demonstration testing at Rokko test center for advanced energy systems," in Proceedings of 23rd IEEE PESC, pp. 1063-1067, 1993.
[31] M. Ropp, K. Aaker, J. Haigh, and N. Sabhah, Using Power Line Carrier Communications to Prevent Islanding, in Proc. 28th IEEE Photovoltaic Specialist Conference, pp. 1675-1678, 2000.
[32] W. Xu, G. Zhang, C. Li, W. Wang, G. Wang, and J. Kliber, "A power line signaling based technique for anti-islanding protection of distributed generators—part i: scheme and analysis," IEEE Tran. Power Delivery, vol. 22, no. 3, pp. 1758-1766, July 2007.
[33] A. Kitamura, M. Okamoto, F. Yamamoto, K. Nakaji, H. Matsuda, K. Hotta, Islanding phenomenon elimination study at Rokko test center, in Proceedings of the 1st IEEE world conference on photovoltaic energy conversion, pp. 759-762, Hawaii, December 1994.
[34] T. Funabashi, K. Koyanagi, R. Yokoyama, A review of islanding detection methods for distributed resources, Power Tech Conference Proceedings, 2003 IEEE Bologna, vol.2, no., pp. 6 pp. Vol.2-, 23-26 June 2003.