On active anti-islanding techniques: survey

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ABSTRACT

The phenomenon of feeding loads from any distributed generators (DGs) with a total disconnection of utility grid at the point of common coupling is called islanding. The DGs are usually independently controlled. Hence, when the islanding problem occurs, the electric utility loses the control and supervision over that section of the power grid. Furthermore, prolonged islanding can prevent reconnection to the power grid and may cause damage due to voltage and frequency excursions. Therefore, the islanding detection, which is also called anti-islanding (AI), is one of the most critical aspects of the integration of DG sources into the power grid. In this paper, a comprehensive survey on the local AI techniques is illustrated, especially active type which is used for improving the performance regarding the size of the non-detection zone and detection speed. Extensive comparisons are provided to demonstrate the effectiveness of each technique.

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1. INTRODUCTION

Increasing the demand of energy over the world and in addition to the limited resources for traditional power generation methodologies, different distributed generators (DGs) resources such as wind turbines, solar energy, fuel cells, water turbines and micro-turbines, are utilized in modern distribution systems [1], [2]. As shown in Figure 1, the DG source at the end users generates a reverse power flow at the utility side which will affect the protection of utility. Nevertheless, sources of DG have been become increasingly popular because of its ability to solve several issues associated with conventional power systems [3]. The DG sources are distinguished by reduceing the demand on the transmission system, where the DGs are distributed near the load so, the reliability of the power grid is increased. Furthermore, the DGs have a lot of benefits such as reducing power losses, improving the voltage profile, enhancement of power quality (in some cases) [4].

On the other hand, some disadvantages affect the safety of the utility grid and the main dangerous problem is the islanding which is considered an undesirable phenomenon leads to power quality problems for the customer's loads, safety hazards for the humans which are working for maintenance the utility. In addition to, the islanding can cause a change in the fault level, frequency and voltage control problems, and power supply facilities as a result of unsynchronized recloser and damage to power generation [1]-[3]. Hence, according to the IEEE standards, this phenomenon should be detected within less than 2s.

As shown in Figure 2, the islanding phenomenon happens in conjunction with opening of the circuit breaker (CB). The entire left side includes the generation and loads become isolated and the solar generation system continues to energize these isolated loads. This situation degrades the quality of power and creates an unsafe condition in the system.

(a) Traditional distribution system

(b) Modern distribution system

Figure 1. Power distribution system (traditional and modern)

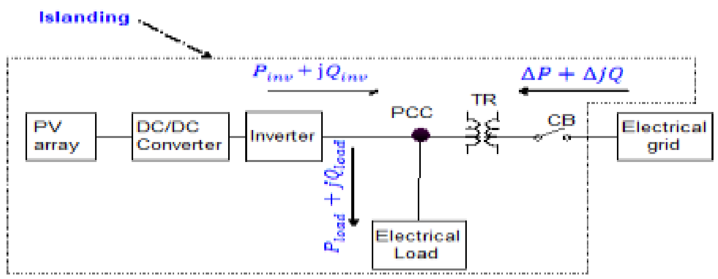


Figure 2. Model of a grid-disconnected DG source (islanding phenomenon)

There are two main techniques which are used for detecting islanding phenomenon, the remote and the local techniques, where the local technique is divided into passive and active as shown in Figure 3. The basic idea of the remote techniques is illustrated as shown in Figure 4 by transmitting a low-energy signal continuously between the transmitter (T) founded in the grid side and the receiver (R) founded in the DG side. When this communication is failure, the receiver sends a stopping signal to the inverter and/or a switch (included in the receiver) should be opened for isolating the load from the DG [5].

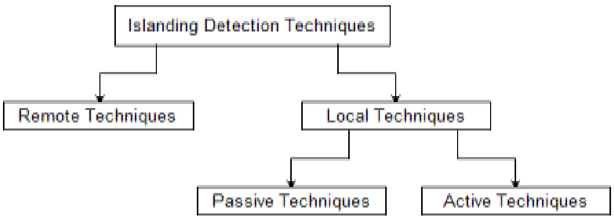


Figure 3. Classification of Islanding Techniques

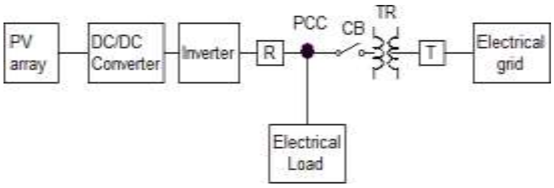


Figure 4. The general structure of the remote AI technique

The advantages of this technique are the output power quality of the inverter is not decreased, the ability of working in areas with high density of DG, it does not have non-detection zone (NDZ) and doesn't depend on the system size. Moreover, there some disadvantages such as the receiver and transmitter cost may be too high, it requires multiple signal generators and this has a high cost in comparison with a simple radial system, under abnormal conditions it has NDZ if some loads are operating. It needs a reliable communication system [5], [6] which requires enormous infrastructure and hence, extremely excessive cost. Consequently, these techniques are rarely used on a small scale.

This paper surveys the recently developed AI techniques applicable to inverter-based DG sources which are the largest and the fastest-growing sector [6]. The survey is organized as follows: The issue of islanding is discussed in Section two. Comparative AI techniques and the advantages and disadvantages for each technique especially the problem of NDZ and the impact of them on the power quality are presented in Section three. Finaly, the conclusion and an outlook for future research in this area is collected in Section four.

2. ISSUES OF ISLANDING

Intentional islanding is occurred by humans, who have authority on the system for maintenance or emergencies, but there is unintentional islanding that is happened without any interference from humans; both cases have many disadvantages as listed, a) safety issues arise for all humans who are working on the line, where they could have hazards as a result of the generated power from DG sources in case of the disconnection of power from a utility grid, b) the values of frequency and voltage may vary away from the standard permissible level, and c) unintentional reclosing may lead to a desynchronization of DG, which causes unexpected mechanical torque can destroy the generators [4].

Based on what has been put forward and the previous shortcomings, islanding must be detected quickly and accurately. To have the best AI method, two main aspects must be discussed, the NDZ and quality factor (Q factor) [7], [8]. The NDZ is defined by the interval which the islanding phenomenon is failed to be detected by traditional AI techniques [9]. As shown in Figure 5, the NDZ is the zone created in case of similarity between the local load consumed power and the DG generated power. In this case, both a reactive power variation (ΔQ) and a real power variation (ΔP) shown in Figure 6, are zero. Thus, the utility grid does not supply any power and hence, the disconnection of utility could not be detected, even with using over/ under frequency (OF, UF) and voltage (OV, UV) relays.

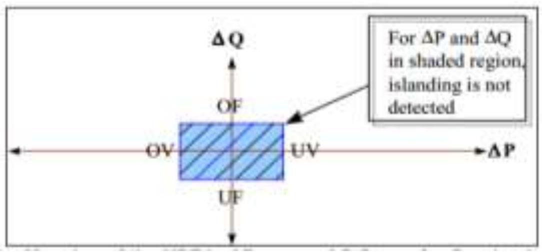


Figure 5. NDZ in ΔP *versus* ΔQ for over/under frequency and voltage

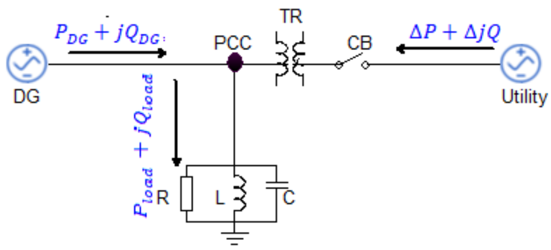


Figure 6. RLC load between DG and utility

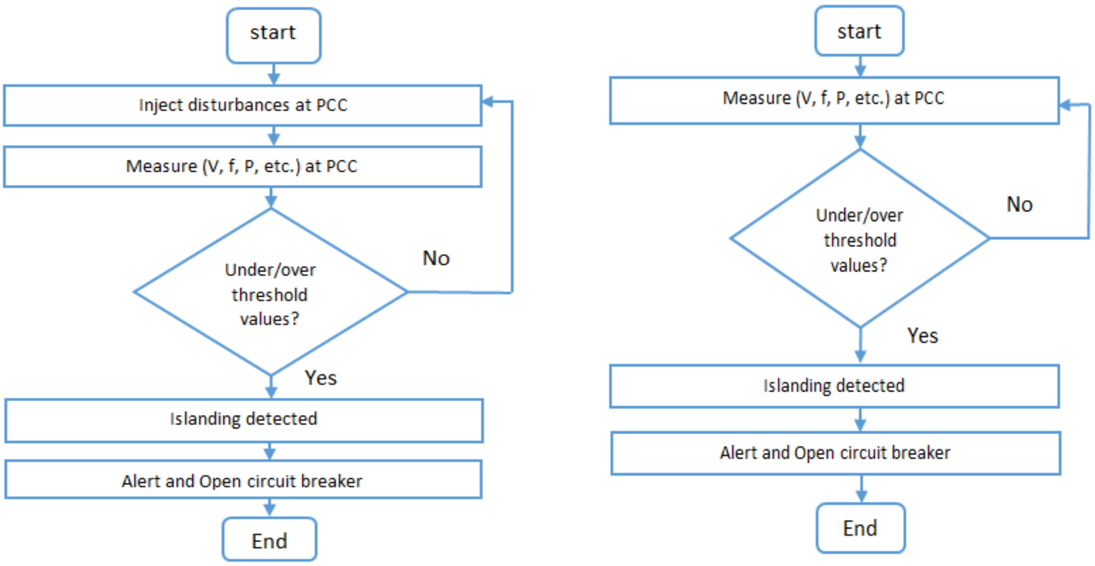
Therefore, the NDZ is regarded as the main parameter for detecting islanding. The other aspect is the quality factor Q_f in (1) for any known frequency defined as the ratio of maximum stored energy over energy consumed per cycle times multiplied by two [10]. The Q_f factor can be used to represent the relationship between stored energy and the dissipated one in the RLC load, which located between DG and utility Grid. As shown in Figure 6, the single line diagram of a grid is connected to the DG source. The real power (ΔP) and reactive power (ΔQ) are delivered. The P_{DG} and Q_{DG} are the real and reactive power delivered by the DG source respectively. Similarly, the P_{load} and Q_{load} are the real and reactive power absorbed by the load, and its values are affected by the potential of local loads within the isolated part of the system.

$$\text{Quality factor } (Q_f) = 2 * \frac{Energy\ stored}{Energy\ consumed\ per\ cycle} \quad (1)$$

In particular, a lot of AI methods suffer from NDZ especially the passive one. However, the smaller NDZ is preferred [6]. The relation between the Q_f factor and NDZ is proportional, that means, any decreasing of the NDZ will improve the time response of islanding detection, but it will lead to a decrement in Q_f factor. Obtaining the best results for all parameters becomes the core of the research area nowadays.

3. AI TECHNIQUES

To resolve the problem of islanding, the AI techniques which are categorized to remote and local will be used [6]. Under these two categories, a lot of control techniques are provided depending on the method of detection for each one. As shown in Figure 7, the operation of local AI techniques is classified into passive and active techniques. Passive methods depend on monitoring several parameters such as frequency, current and voltage. Then setting thresholds for these parameters can help for islanding detection if the value of any parameter is out of range. The implementation of this technique is fast, easy, more uncomplicated and has no disturbance in the system, despite all these advantages, it has a significant NDZ [11] which is considered the primary defect in this technique even we use traditional passive techniques or smart techniques [12]-[18].



(a) Active techniques (b) Passive techniques

Figure 7. Flow chart of local AI Techniques (a) passive (b) active

The challenge of the passive methods is how to select the convenient threshold [19] which is matched with the IEEE 1547 standard. Table 1 summurizes this standard in order to sure that the islanding has happened or there is another disturbance affects the system. The mechanism of detecting islanding for passive techniques is shown in Figure 7 (b). This paper will be focused on active AI techniques and discussed in detail in the following subsection.

Table 1. Standard IEEE 1547 for AI Techniques

Parameters	Standard
Range of Voltage	88% ≤ V ≤ 110 %
Range of Frequency	49 HZ ≤ f ≤ 50 HZ
Maximum time for islanding detection	2 second
Total Harmonic Distortion (THD %)	≤ 5 %

Active methods introduce intentional disturbances to the rest of the circuit and then analyze the feedback to decide whether there is an islanding or not [20]. The mechanism of detecting islanding for Active techniques is shown in Figure 7 (a).

Despite, the active methods have small NDZ, but unfortunately it leads to decreasing power quality of thesystem. In addition to, these methods may change the magnitude of the output for the inverter either frequency or current. Although, there are some active methods can detect islanding without decreasing power quality, it will require using many controllers that will increase the complexity for the implementation and more expensive than the other local techniques [21]-[41]. AI detection techniques are explained in detail in the rest of this subsection.

a. Active frequency drift (AFD) technique

In this techniue, some disturbances of the current signal are injected into the point of common coupling (PCC) depending on V_{PCC} which follows the fundamentals of I_{inv}, where V_{PCC} and I_{inv} represent the PCC voltage and inverter output current respectively. Hence, in the grid-connected mode, this distortion does not affect the current and voltage. Therefor, the frequency of the system has the same frequency of the grid. In the other hand, the grid-disconnected mode (islanding condition) has distortion leads to a phase difference between the current and voltage. Hence, this difference leads to a drift in frequency that obligates the UF/OF relays to cutoff the DG from the rest of the circuit. As shown in Figure 8, it is a comparison between a waveform of distorted DG output current with undistorted sine waveform. The chopping factor C_f is used to calculate the intensity of the disturbance as in the (2).

$$C_f = \frac{2t_z}{T} \qquad (2)$$

Where, T is the voltage period of the grid and t_z is the dead time. However, this technique can easily be implemented using a microprocessor. It affects the power quality [42]-[53].

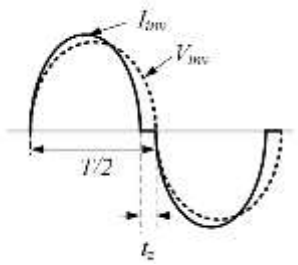


Figure 8. Waveform of AFD Technique [48]

b. Slip-mode frequency shift (SMS) technique

In this Technique, SMS is based on a positive feedback destabilization for the output of the inverter in order to detect islanding state which changes relative to the grid voltage. In grid disconnection mode, it will obligate the frequency of the voltage at PCC to deviate from the standard value. In contrast to the other active methods, SMS is characterized by a limited NDZ and assumed as an efficient method for AI detection. In contrast with the other methods that depend on positive feedback, SMS has some drawbacks such as perturbation in the phase shift which can cause noise, quantization error and, measurement error. By using extra phase shift known as the improved slip mode frequency shift (IM-SMS) to overcome all drawbacks of SMS, besides easy implemenationt, simpler and more reliable [54].

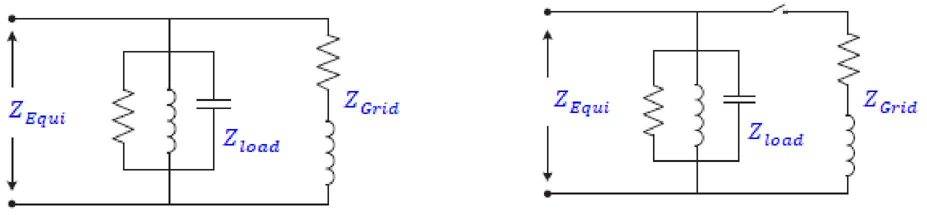
c. Impedance measurement technique

This technique is classified as similar to a passive technique. It monitors the variations of the system impedance which occur by islanding. Furthermore, this technique will lead to a reduction in voltage and current as a result of temporarily parallel connected inductor across the utility grid, but it nearly has not NDZ, especially in the single-inverter case [55].

In grid-connected mode, in case of a large difference between the harmonic frequency impedance of the DG and the load, as shown in Figure 9 (a), the equivalent impedance will be smaller due to the existence of low grid impedance Z_{Grid} that is parallelly connected with the load impedance Z_{Load} as shown in (3). However, in the case of islanding mode, there is only one way to flow, so any difference can force the under/over voltage protection relays to work and stop the inverter's operation as.

$$Z_{Equivelant} = \begin{cases} Z_{Load} \parallel Z_{Grid} & if\, grid\ connected \\ Z_{Load} & if\ islanding \end{cases} \qquad (3)$$

These experimental studies prove that the method of impedance measurement used for detecting islanding may have small NDZ in the single-inverter cases, but the main disadvantage appears in parallel multiple inverters cases, as each one forces a slightly different signal into the line [56]. Adding a variable length in phase shift will lead to an increase in the accuracy for the single-inverter case, but unfortunately, this enhancement will add a few numbers of harmonics on the output of the inverter. Hence, other AI methods are used to solve the drawbacks of impedance measurement techniques.



(a) Mode of grid connection (b) Mode of grid disconnection

Figure 9. Equivalent impedance within grid connection and disconnection mode

d. Sandia frequency shift (SFS) technique

The SFS technique is known as a modified active frequency drift (AFD) technique which depends on a feedback by injecting a small phase shift at the output current of the inverter. So, there is a deviation between the inverter output current and power system frequencies. The (4) shows the chopping factor that is proportionally related to the difference between the utility and inverter frequency.

$$C_f = C_{f0} + \mathrm{K}(f_0 - \mathrm{f}) \tag{4}$$

Where C_{f0} is the chopping factor at zero frequency error, K is the accelerating gain, and f_0 and $, f$ are the PCC measured frequency and line one, respectively. The C_f becomes low in case of that the frequency error equals zero as the utility stabilizes the voltage at PCC through a reference for phase and frequency. In the case of grid connection mode, a small variation in frequency but has a negligible effect. However, in the case of islanding mode, PCC frequency increases then the frequency error increases, which in turn raises the frequency of the inverter. The process will persist until happening the matching for the limits of threshold and islanding is detected.

Although SFS has a reduced NDZ and is the most convenient among the other active methods, it reduces the output power quality of the inverter. Moreover, it introduces noise and harmonics [57]. So, detecting the islanding phenomenon has done in this case by the under/over frequency protection relays and take action to stop the inverter's operation [57]-[63].

e. Sandia voltage shift (SVS) technique

In this technique, the SVS used for preventing the islanding based on the method of positive feedback, which mainly depends on the PCC's voltage amplitude. In the case of grid-connected mode, there is no effect on the power system, but when disconnection occurs between the utility grid and DG, it will lead to a reduction in PCC voltage. So, detecting islanding phenomenon, in this case, can be done by using the under/over voltage protection relays and take action to stop the inverter's operation [64]. This Technique has a smaller NDZ than the other techniques in addition to a fast detection speed if the convenient accelerating factor is chosen.

The recapitulation of the various local islanding detection methods (IDMs) and a comparison between passive and active techniques with respecting to its classification, concept, detection time, cost which affect on the power quality and the size of NDZ. In these cases, detection of islanding will be presented as shown in Table 2 as it characterizes the various IDMs in terms of their merits, demerits, and other performance capabilities. Hence, from Table 2, the SFS method is the fastest method for detecting islanding according to [61] but unfortunately, this method leads to a current distortion.

4. CONCLUSION

This paper presented a comprehensive review for several updated active islanding detection techniques during the connection between the utility grid and PV systems. Based on the whole discussion and trends at this point, local AI methods are classified into passive and active. The passive method depends on displaying some parameters of the system as frequency and voltage. But the active technique depends on injecting some perturbations on the output current or voltage of the inverter. Hence, this paper focused on the active techniques. According to the detailed comparison between active methods, it can be noticed that these methods are featured by small power degradations, faster response, high reliability and can decrease NDZ. But these techniques are not easy for implementation as the passive ones. Passive methods do not affect output power quality and simple to implement but have large NDZ. So, it is recommended to use a hybrid technique that incorporates local techniques and artificial intelligence to have accurate islanding detection under various load conditions, which is predicted to be faster than all other methods and achieves the standard time according to IEEE 1547.

APPENDIX

Table 2. A comparison of local islanding detection methods

	Operation principle	Classification	Ref	Concept	NDZ	DG system	Detection Time	Disadvantages	Effect on power quality	cost	Detection failure
Active Techniques	Adding a disturbance signal to the grid	AFD	59	Frequency Variation	Small	Inverter based	928 ms	fails for high Q_f loads	Decreases the power quality of the system	Average cost	Yes, in high quality factor
		SMS	47	A variable phase difference between the current and voltage		VSC	0.37 s	Current distortion			
		Impedance Measurement	55	Detect the variation of utility impedance		Synchro nous	---	False tripping			
		SFS	61	Zero-current segment per half cycle		VSC	0.10 s	Current distortion			
		SVS	64	Same as SFS except for voltage		Inverter based	0.231 s	Voltage distortion			

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