

Islanding Detection Techniques for Distributed Energy Resources-Review

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ABSTRACT: Distributed generators (DG) present in the electrical power system may continue to supply the local area even in the case when the main grid gets disconnected, this is called islanding. Such islanded operation may result into serious safety hazards to the personnel and the equipment as the power lines which are presumed to be disconnected are still energized by nearby distributed generators. The issue is still more critical when large number of DGs are interfaced through power electronic converters having short overload operating capability. Hence, it is indispensable to identify such islanding condition and to prevent DGs from energizing the lines. This paper presents the over view of different islanding detection techniques for DG. Comparison of these techniques is also provided in the paper.

KEYWORDS: Distributed generation (DG), Islanding, Point of common coupling (PCC), Non Detected Zone (NDZ).

I. INTRODUCTION

From last few years, there is rapid increase in the energy consumption around the world. The inadequateness of the conventional energy resources, rising public awareness about environment issues, progress in the power deregulation and new innovation in power electronic devices have motivated people to move from the traditional energy resources to renewable energy resources like solar, wind and fuel cell [1],[2]. The concept of use of renewable energy resources can be used for the distributed generation which means generating power at distribution level.

Distributed generation can be defined as the generating station other than the centralized generating station which is placed usually at the customer site. The DG in the distribution network has the several benefits like it reduces transmission and distribution (T&D) line losses, reduces necessity of building new T&D lines, increases reliability of the electrical power system, improve power quality, improve voltage profile etc [3]. But the presence of DG in the system may result into several issues and one of the major issues is islanding. Islanding is the situation in which part of the EPS is disconnected from the remainder of the power system, but still that isolated portion energized by the DG connected to it [4].

Although there are some advantages of operating system in island mode, but there are several drawbacks of it. Some of them are as follows [3], [4]

- Significant variation in the voltage and frequency at PCC and it may not possible to maintain them within the permissible limit.
- Safety hazards to field engineers and maintenance personnel as DG sources are continuously supplying power to system even after DG is disconnected from the main grid.
- Instantaneous reclosing could result in out of phase reclosing of DG.
- Automatic reclosing may fail to function if the DG source keeps on feeding the fault in islanding mode. It may create interference in automatic or manual restoration of normal service.

Due to above issues with islanding, it is necessary to detect the islanding condition as quickly and accurately as possible. Different remote and local islanding detection techniques are explored in the next section of the paper.

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II. ISLANDING DETECTION TECHNIQUES

Islanding detection techniques can classify in remote and local techniques and local techniques can again classify as passive and active techniques as shown in Fig. 1. These techniques monitor the DG side parameters and/or grid side parameters to detect an islanding condition.

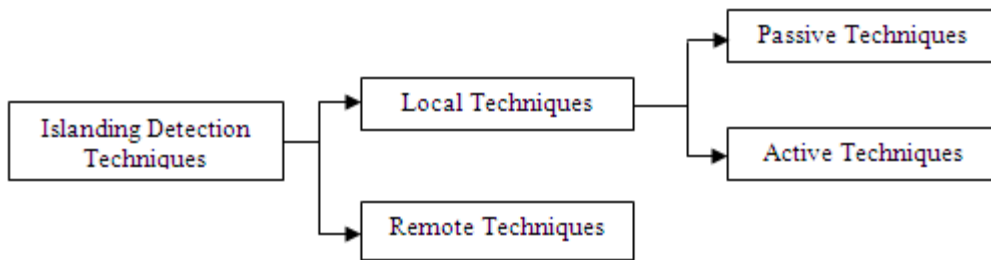


Fig. 1 Islanding detection techniques

A. Passive Islanding Detection Techniques

Passive methods monitor parameters such as variations in the voltage, frequency, harmonic distortion etc. to detect the islanding condition. When island occurs, great variation in these parameters can be observed. To differentiate islanding condition from the other disturbances, special care must be taken while setting threshold values. These methods are fast and they don't introduce disturbances in the system to detect islanding condition. But they have large non detected zone in which the islanding techniques fails to detect islanding condition.

i. Under/Over Voltage and Under/Over Frequency

In this method parameters like voltage magnitude and frequency at PCC are measured to identify islanding situation. When islanding occurs, these parameters crosses their threshold limits and that variation in the parameters is used to detect islanding condition. Once islanding situation has been detected, the DG must cease its operation [5].

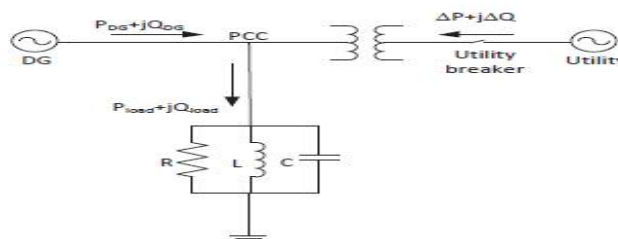


Fig. 2 A system model of the grid connected DG

At the PCC,

$$\Delta P = P_{load} - P_{inv} \text{ and } \Delta Q = Q_{load} - Q_{inv}$$

The value of ΔP and ΔQ decide the behaviour of the system when DG is disconnected from the utility grid. If in the system $\Delta P \neq 0$ and DG is disconnected from the grid, at that time large variation of the frequency at PCC can be observed and accordingly UFP/UFP will operate to cease operation of inverter. If $\Delta Q \neq 0$, then during islanding large variation in the voltage magnitude can be observed and UVP/OVP will operate. However this method has large NDZ in which it fails to detect islanding condition, particularly in the case when ΔP and ΔQ are near to zero [5],[6].

ii. Voltage Phase Jump Detection

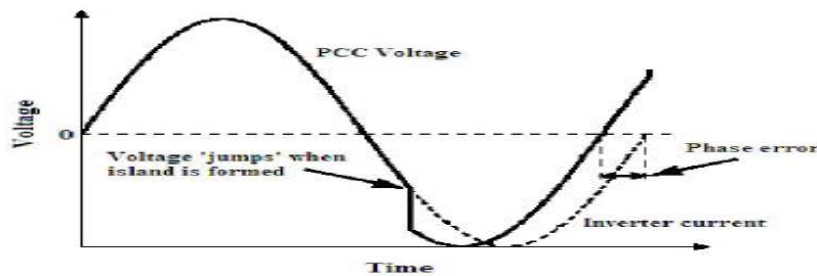


Fig. 3 Operation of voltage phase jump detection method

In this method phase difference between voltage at PCC and inverter output current is observed. The inverters for PV are generally operated at unity power factor. Under normal grid connected condition voltage at PCC and inverter output current are in synchronism that means zero or near to zero phase difference. When islanding occurs, “jump” in the phase of the PCC voltage as seen in Fig. 3 can be observed. This variation in the phase difference is used to detect islanding condition. This method has smaller NDZ than OUV/OUF protection method. But this protection scheme may falsely trigger the protection devices under non islanding condition [7].

iii. Voltage Unbalance and Total Harmonic Distortion

This method uses two parameters such as voltage unbalance and THD of the current for detecting islanding condition.

Typically, the harmonic content of the signal due to switching operation of the PV inverter is absorbed by low impedance grid. In the absence of grid, the harmonic current will pass through islanded load, results in increase harmonic level of the inverter terminal voltage. This variation in THD can be used to detect islanding condition. However, threshold setting for this technique is difficult as inclusion of non linear load in the system results into increase harmonic level even though grid is connected and this may lead to false tripping of protecting device [5].

This limitation of THD based detection technique leads to use voltage unbalance as an islanding detection parameter in combination with THD.

$$\text{(Voltage Unbalance) } VU = \frac{V_{NS}}{V_{PS}}$$

V_{PS} and V_{NS} are the positive and negative sequence voltages of the DG terminal voltage. When island occurs, change in the topology of the power system results into change in VU, even for small amount of power mismatch [5]. Therefore, voltage unbalance parameter (VU) along with the THD parameter is used to detect islanding condition. This technique is expensive and applicable to 3- phase system only.

iv. Rate of Change of Frequency df/dt

This method monitors the voltage waveform at PCC and calculates df/dt. Large value of df/dt can be observed during islanding. The threshold limits must be selected such that the scheme can differentiate between the island and the normal load change condition. The threshold setting for this method is 0.1-1.2 Hz/s. This method may fail to detect islanding condition when there is small power mismatch between DG’s capacity and local load [4], [8].

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v. Rate of Change of Power dp/dt

During islanding, dp/dt , is much larger than the dp/dt during normal grid connected condition for same rate of load change. This method is much more effective for unbalance load rather than balanced load [3], [4].

vi. Rate of Change of Frequency over Power df/dp

In this method df/dp is measuring parameter to detect islanding. For small power generation capacity system df/dp is larger than that of system with larger power generation capacity. For small power mismatch between DG's capacity and local load df/dp is much more sensitive than df/dt to detect island [3], [4].

B. Active Islanding Detection Techniques

In this method perturbations are injected into the inverter output current waveform and accordingly amplitude, phase and frequency will change. During normal grid connected condition, these disturbances are absorb by low impedance grid but during islanding condition these disturbances are design to drive the operating point of the islanded network to exceed the threshold limit of the protective devices.

i. Slip Mode Frequency Shift (SMS)

In this method, a positive feedback is applied to the phase of the PCC voltage to destabilize the inverter during islanding. Shifting the phase of the voltage results in change in frequency. From the graph in Fig. 4, it can be seen that, around the utility frequency, the phase of inverter curve increases rapidly than phase of the load [7].

During normal grid connected condition, inverter operates at frequency ω_0 with zero phase angle. When utility is disconnected, the frequency of the PCC voltage will change and accordingly phase response curve increases the phase angle error and hence inverter became instable to operate at utility frequency ω_0 . This instability further amplifies the perturbation in the frequency and thus system will move to another operating point either ω_1 or ω_2 which is the frequency outside the range of OFP/UFPP. Implementation if this method is easy and has comparatively smaller NDZ than passive methods. But for some RLC load which has phase of load increase at faster rate than the phase of inverter like the load which has high Q factor, this method fails to detect islanding condition[6],[7].

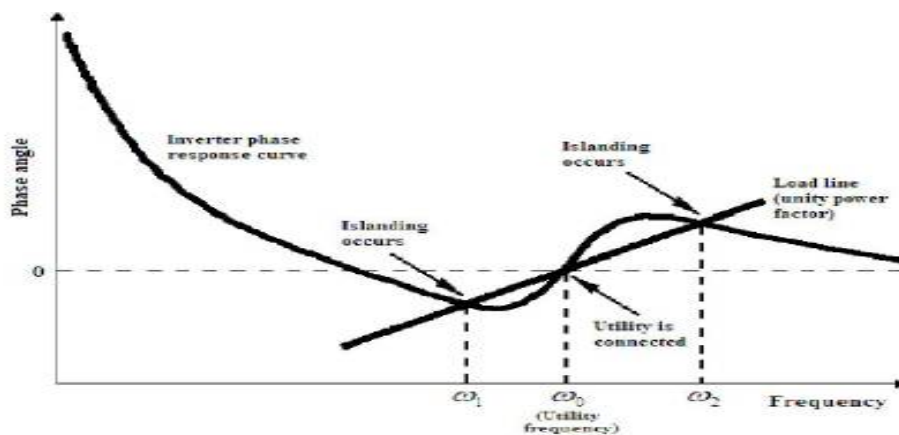


Fig. 4 Operation of slip mode frequency shift method

ii. Active Frequency Drift (AFD)

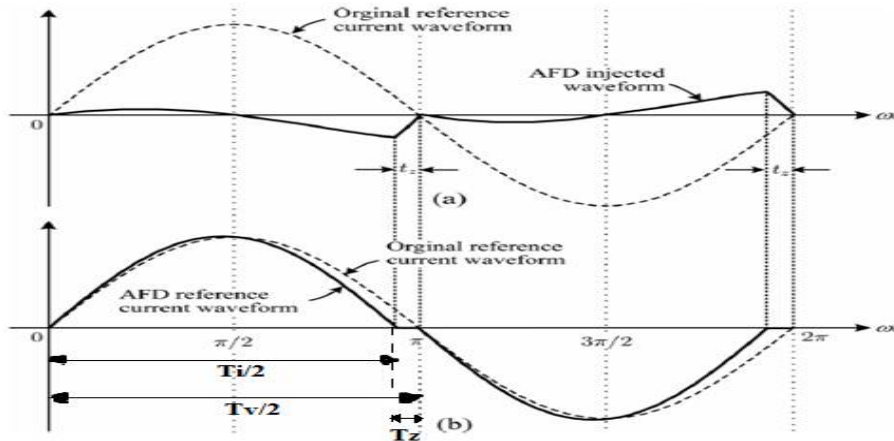


Fig. 5 (a) Original and AFD reference current waveform (b) Original and injected reference current waveform

In this method slightly distorted inverter output current as shown in Fig. 5(b) is injected into PCC. In the Fig. 5 T_v and T_i are time period of the utility voltage and inverter output current. T_z is the zero conduction period. When grid disconnects, the frequency of the PCC voltage will drift up or down continuously as inverter operating at the unity power factor tends to seek the resonance frequency of the local load. This variation in the frequency can be used to detect islanding condition [9]. We can define chopping factor as follows,

$$cf = \frac{2T_z}{T_v}$$

The chopping factor has low value during normal grid connected condition but when grid disconnects chopping factor is high as there is large phase error between PCC voltage and inverter output current [5]. For purely resistive load this method is very effective but it may fail for other loads.

iii. Sandia Frequency Shift (SFS)

This method is extension of the AFD method. In this method positive feedback is applied to the frequency at PCC. In this method chopping factor is somewhat modified than AFD method as below [5], [8]

$$cf = cf_0 + K(f_{PCC} - f_{line})$$

where, cf_0 is the chopping factor when there is no frequency error, K is the gain of controller, f_{PCC} and f_{line} are frequency at PCC and line frequency respectively.

When grid is connected, a minor change in the frequency due to load variation in the system does not affect the strong grid. But during islanding condition, frequency error in the above equation will increase as frequency at PCC will change. This result in increase in chopping factor and it will further vary the frequency at PCC and it will continue till it reaches to threshold limits set for frequency protection [5].

SFS method has smallest NDZ and most effective. This method reduces the output power quality of the inverter and positive feedback makes this method susceptible to noise and harmonics [8].

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iv. Sandia Voltage Shift (SVS)

In SVS method positive feedback is applied to the amplitude of the voltage at PCC. During normal condition there is little or no effect due to load variation in the system. During islanding, reduction in the amplitude of the PCC voltage results into reduction in the inverter output current due to load impedance's relationship. This reduction in the current further reduces the voltage till detect by the UVP. It is possible to either increase or decrease in the PCC voltage leads to OVP/UVP to trip [5].

v. Automatic Phase Shift (APS)

AFD and SMS methods have NDZ for some parallel RLC loads. This APS method reduces the problem with AFD and SMS methods. In this method positive feedback is applied to the phase angle of the inverter output current [5].

In this method, at k^{th} zero crossing of the terminal voltage, frequency of the previous voltage cycle is first measure. The starting angle $\theta_{\text{APS}}[k]$ of the inverter output current is updated according to $f[k-1]$ as given by below equation.

$$\theta_{\text{APS}}[k] = \left(\frac{f[k-1] - 50\text{Hz}}{50\text{Hz}} \right) \times 360^\circ + \theta_0[k]$$

If steady state frequency of the terminal voltage reaches before OFP/UFP triggers, the additional phase shift angle θ_0 is change according to below equation,

$$\theta_0[k] = \theta_0[k-1] + \Delta\theta \times \text{sgn}(\Delta f_{\text{ss}})$$

where, $\Delta\theta = \text{constant}$,

$\Delta f_{\text{ss}} = \text{Change in steady state frequency}$,

$\theta_0[k] = \text{Additional phase shift}$

$\text{sgn}(\Delta f_{\text{ss}}) = 1, \quad \Delta f_{\text{ss}} > 0$

$0, \quad \Delta f_{\text{ss}} = 0$

$-1, \quad \Delta f_{\text{ss}} < 0$

Each time additional phase shift is introduce as the frequency of the terminal voltage stabilizes to new operating point. When islanding occurs, this method keep deviating the frequency of the PCC voltage until OFP/UFP will operate. This method works for both pure R and RLC load but for non linear load this method gives error [3], [6].

C. Remote Islanding Detection Techniques

These methods are communication based methods and monitor utility side parameters to detect islanding condition. These methods are most reliable and accurate but they are costly.

i. Transfer Trip Method

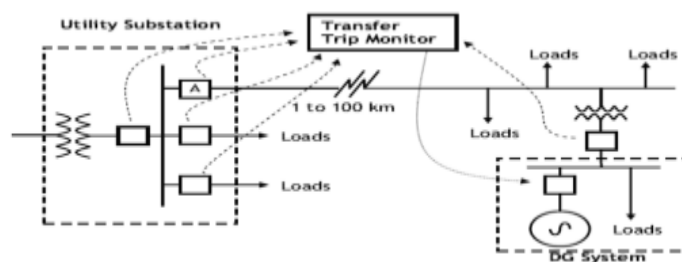


Fig. 6 Transfer trip islanding detection

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In this method status of all the utility circuit breakers and reclosers are being monitor using SCADA (Supervisory Control and Data Acquisition) system. The concept of this method can be understand from Fig. 6. Islanding condition can be detected by the status of the circuit breakers and according to it necessary signals are sent to inverter to stop its working [3], [4].

ii. Power Line Signalling Method

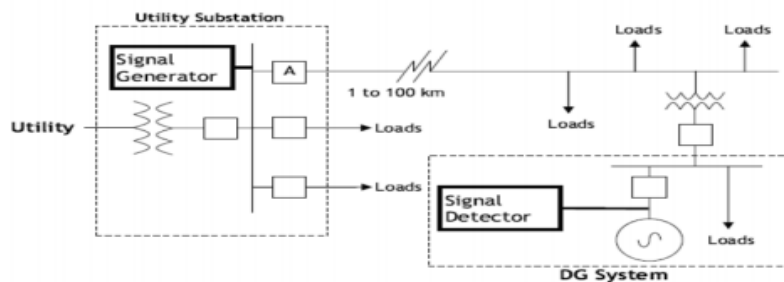


Fig. 7. Power line signalling islanding detection

In this method power line is used as the signal carrier. For this method signal generator need to place at utility circuit breaker and signal detector is placed at DG as shown in Fig. 7. The signal is continuously broadcasts to all DGs in the network. During grid connected condition signal detector at DGs continuously receives the signal but during islanding no signal will be detected by the signal detector at DG and inverter stop working [3], [4].

III. ADVANTAGES AND DISADVANTAGE OF ISLANDING DETECTION TECHNIQUES

Islanding Detection Techniques	Passive Techniques	Active Techniques	Remote Methods
Advantages	<ul style="list-style-type: none"> • Smaller detection time • Do not introduce any perturbation in the system • Do not degrade output power quality of the DG • Accurately detect islanding condition when there is large mismatch between DG capacity and local demand 	<ul style="list-style-type: none"> • Small NDZ • Even for perfect match between DG capacity and local demand in the system it can detect islanding. 	<ul style="list-style-type: none"> • Most reliable
Disadvantages	<ul style="list-style-type: none"> • Threshold setting is difficult • If the setting is to aggressive then it could results in nuisance tripping • Difficult to detect islanding when DG capacity and local demand are closely matched. • Large NDZ 	<ul style="list-style-type: none"> • Introduce perturbation in the system • Output power quality of the system degrades and if significant enough it will degrade the stability of the system • Detection time is slow 	<ul style="list-style-type: none"> • Expensive to implement

IV. CONCLUSION

Remote methods of islanding detection are superior to local islanding detection methods, however at the increased cost and level of sophistication. Local methods are more preferred as they are dependent on the measurement of local

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parameters, free from noise in communication, cheaper etc. Review of several passive and active islanding detection methods that rely on measurement of local parameters, suggest that active methods are superior to the passive detection methods even when there is not mismatch between power generated and demanded in the local island. In the active methods as disturbances are introduced intentionally to detect if the island is created or not, it raises the issue of power quality. However, the magnitude of such disturbances and hence, the effect on power quality is not that significant.

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