

A Review of Anti-islanding Protection Methods for Renewable Distributed Generation Systems

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Abstract: *Islanding detection of distributed generations (DGs) is one of the most important aspects of interconnecting DGs to the distribution system. Islanding detection techniques can generally be classified as remote methods, which are associated with islanding detection on the utility sides, and local methods, which are associated with islanding detection on the DG side. This paper presents a survey of various islanding detection techniques and their advantages and disadvantages. The paper focused on islanding detection using a conventional and intelligent technique.*

Keywords: *Anti-islanding Detection, Sandia Frequency Shift (SFS), Non Detection Zone (NDZ), Active Methods, Passive Method, Intelligent Methods, Artificial Immune System (AIS).*

1. Introduction

Distributed Generation (DG) becomes one of the most important trends of power system engineering. DG is a small electrical power generation devices that provides electric power at or near the load site; it may be connected to the distribution system or to the customer's facilities or both. Generating power near to load site reduces the cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution. It helps on the enhancement of the conventional electric power system. DG has the ability to adopt different sources of energy such as solar, wind, methane, fuel cells, gas turbines, and combustion engines. By having DG, the source is closer to the load and therefore will have fewer losses, provide voltage support, and have more controllability of the system.

Integrating DG with the low voltage distribution system, may results in some of problems one of them is islanding. Islanding occur when a part of distribution system becomes electrically isolated from the rest of the power system and still energized by the DG that connected to it. Normally, the distribution system doesn't have any sources of active power generation in it, and when a fault occurs in the upstream transmission line it doesn't get power. However, when the DG is connected to the

distribution system, this assumption is changed. At the presence of islanding, DG must be disconnected from the grid. Islanding can be intentional or non-intentional. The islanding is called intentional if the grid outage is predetermined and scheduled as maintenance services. However, the non-intentional islanding caused by accidental shutdown of the grid. As there are various issues with unintentional islanding, it has more of interest. The island can occur for the following reasons: As a result of a fault that is detected by the utility protection equipment, and results in opening a fault interrupting device, but which is not detected by the DG inverter. As a result of accidental shut down of the normal utility supply by equipment failure; As a result of utility switching of the distribution system and loads, such as for maintenance operations; or, As a result of human error. IEEE Std.929-2000 limits the voltage, frequency and THD for efficient islanding detection [1].

2. Islanding detection methods

Monitoring the system and DGs parameters may aid in deciding that whether an island occur or not then the island can be detected. Islanding detection methods can be classified into remote and local methods. The local methods can divided into passive, active, hybrid and computational intelligence based techniques. This can be discussed in the following points.

2.1. Remote Islanding Detection Techniques

These techniques depend on communication between utility grid and DGs. Islanding is detected based on the status of the utility connected circuit breakers. In these methods, each DG site has a receiver, and all the circuit breakers in the line leading to the DG site from the utility have transmitters. When islanding occurs a signal is sent to trip the DG depends on monitoring the state of circuit breaker. Although these methods may have high reliability, however they are very expensive to implement. Traditionally only utility owned wires

and channels subscribed from public telephone companies have been considered. Today radio transmitting (FM or AM) and optic fibers can be added to the list [2-3].

2.1.1. Phasor Measurement Units (PMU)

It defines as a Synchrophasor, and rate of change of frequency (ROCOF). A time synchronization source is required for PMU. This may be supplied directly from a time broadcast such as GPS or from a local clock using a standard code. The system consists of two units, one of them at the utility substation and the other at the DG and time is stamped before sending to the receiver. So, it is very easy to determine that DG is synchronized with the grid or not. [4-5]

2.1.2. Comparison of Rate of Change of Frequency (COROCOF)

It compares the changing in frequency at two locations in the grid. A COROCOF relay at a generator set (receiving relay) can distinguish between the local disturbance and the disturbance due to the blocking signal sent by COROCOF sending relay. [4]

2.1.3. Supervisory Control and Data Acquisition System (SCADA)

The use of SCADA for islanding prevention is straight forward. The SCADA system keeps vision on the states of circuit breakers. The information contained in SCADA should be sufficient enough to know that the system is in islanded mode or not. This method based on using sensors and communication networks already in place for normal grid operations. These SCADA networks cover most of the grid. If sensors detect voltages when the grid is disconnected, a warning system can be triggered and the necessary precautions taken. If the inverter itself is connected to the SCADA network, it is possible to exercise some control over the inverter.

This method has the advantage that, it eliminates islanding and provides partial or full DG control by the utility if the system is properly instrumented and the necessary communications links are all available, it should not have an NDZ. It has disadvantages that, it gives a slow response when the system is subjected to one or more disturbances, in the presence of multiple inverters, they would all require separate instrumentation and/or communications links, and

most of small inverters are below the substation levels and this make the implementation of SCADA system is impractical and uneconomical. [6]

2.1.4. Power Line Carrier Communication

This method is used to solve many of the problems associated with inverter-based islanding detection methods. Power line carrier communications (PLCC) involves sending a low energy communications signal along the power line itself. Figure (1) shows a system configuration using PLCC anti-islanding method. A receiver is installed on the customer side of the point of common coupling. A PLCC transmitter located at the utility sends a signal along the power line to the receiver to perform a continuity test of the line. The receiver on the customer side will detect the presence or the absence of the signal. If the PLCC signal disappears, this indicates an islanding event since there is a break in the continuity of the line and the PLCC signal is lost. [6, 7-10]

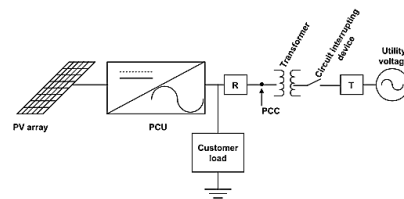


Fig.1. System configuration including a PLCC Transmitter (T) and Receiver (R)

This method has advantages that, it is highly effective in islanding detection as it does not have an NDZ within the range of normally functioning loads, it has no degradation in the PV inverter's output power quality, it doesn't depend on the system size, the type of DG connected and the number of inverters on the system, and it is simple to control and it has high reliability. It has disadvantages that, the transmitter on the utility system that is capable of sending signals through the DGs inverters may be uncommon and quite expensive, but it may be economical for an area has a large number of DGs, when it is implemented in a network system, it requires multiple signal generators and this has a high cost in comparison with a simple radial system, and it has NDZ if some loads are operating under abnormal conditions.

2.1.5. Transfer Tripping Scheme TTS

This method depends on monitoring the status of all circuit breakers and reclosers that may cause

island to the distribution system. This can be achieved by using SCADA system. When a disconnection is detected at the substation, the TTS indicates the islanded area and sends the appropriate signal to DGs to either remain in operation or to disconnect from the grid.

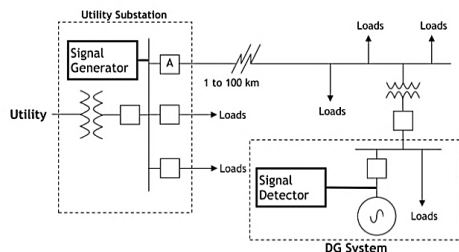


Fig.2. Distributed generation power line signaling islanding detection

This method has advantages that, it is very simple, for radial system with few DGs and limited number of breakers, the system state may be sent directly to the DG from each monitoring point, and if it is correctly implemented, there is no NDZ in operation. The disadvantages of this method are, it requires updating, relocation and reconfiguration if the system grows and becomes complex so the planning for this method is very necessary to consider the system growing and using a large number of DGs, and the DG control as it may lose the control over power producing capability. [6]

2.1.6. Signal produced by disconnect

In this method the DG receive the signal from a small transmitter that is equipped with the utility recloser. This signal is transmitted to the DG when the recloser opens through microwave link, telephone line, optical fiber, or any other mean of communication. This method requires a continuous carrier signal and this prevent a failure of the method due to a malfunctioning transmitter, channel, or receiver. This method has advantages that, it doesn't have NDZ, and this method would allow additional control of the DGs by the utility, resulting in coordination between DGs and utility resources. The disadvantages of this method, they are expensive and complex to implement and hence non-popular, it would be necessary to instrument all series or parallel switches leading to a potential island, and if a telephone link were used, additional wiring to every distributed generator in a potential island would be necessary. This could be avoided using a microwave link, so that inverters in certain locations might have

difficulty receiving the signal without repeaters or boosters. [6, 11]

2.1.7. Impedance Insertion

This method inserts low-value impedance, which is usually a capacitor bank on the grid side of the system inside the potential island, as shown in Figure (3). The switch connecting the capacitor to node B is normally open. When the switch that connects the grid at node B opens, the switch that connects the capacitor closes after a time delay. If the local load is balanced, islanding will occur before the capacitor is connected. Upon connection of the capacitor, the balance will be disrupted and the inverter will shut down. The capacitor will cause a change in current phase and frequency.

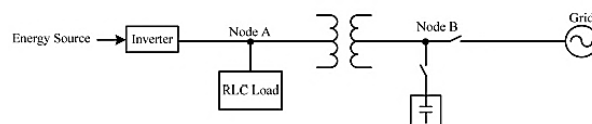


Fig.3. Impedance insertion method with capacitor bank

The purpose of the time delay between the disconnection of the grid and the connection of the capacitor is to eliminate the possibility that the addition of the capacitor will balance the load. If an island is formed before the capacitor is connected, the inverter will shut down prior to the connection of the capacitor. It is possible to use another type of impedance, but capacitors are preferred because the same designs can be used that are implemented in network compensation. This method has the advantage that, it is very effective if the delay is small enough. As mentioned before, these capacitors are already in use in most utilities. If the capacitor is already connected, it can simply be disconnected to prevent islanding, and it has no NDZs exist when it is properly implemented. There are some major disadvantages to this method, it can be expensive, since additional capacitor banks will be needed in most cases, if multiple units are installed at different times, it can furthermore lead to uncertainty as to who should carry the costs of the additional capacitors, the addition of more switches can result in additional islanding branches, the operation time of this method is also much longer than that of most of the other methods. This can lead to equipment damage and the failure to meet certain network compliances, and this method also requires equipment to be installed on the grid side of the PCC, which can require additional permits and costs. [6]

2.2. Local Islanding detection techniques

These methods are depends on measuring the system parameters at DG location such as voltage, frequency etc. These techniques are further classified as:

2.2.1. Passive detection techniques

Passive methods work on measuring system parameters such as variation in voltage, frequency, harmonic distortion. These parameters vary greatly when the system is islanded. The difference between the islanding and grid connected conditions is based on the threshold values set for these parameters. These techniques are fast and don't introduce any disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition. Passive methods are easy to implement and consist of equipment installed on the DG side. Many of these methods are very cost effective, as the relays are already in place for other protective requirements. The biggest challenge with passive detection techniques is setting an appropriate sensor threshold that can identify the difference between islands and natural power system variations. The general consensus is that the currently available passive islanding detection techniques need to be combined with active methods to reduce the non-detection zone, to ensure a higher level of security and dependability. The passive methods do not affect the waveform of the high voltage. This is beneficial since it does not give rise to power quality issues such as voltage dips. Another benefit is that communication is not required to build up the detection system. Communication has traditionally been considered as expensive and vulnerable. Strengths of passive islanding detection are no impacts on PQ and no interference from one islanding detection device on another in the case of multiple inverters since no disturbances are injected. But there are drawbacks that increase the demand for more reliable islanding detection methods. Some of the passive techniques are:

2.2.1.1. Rate of change of Output Power (ROCOOP)

The rate of change of power d_p/d_t at the DG side once it is islanded is much greater than rate of change of output power before islanding for the same rate of load change. This method is more effective for DG with unbalanced load rather than balanced load. [7]

2.2.1.2. Rate of change of frequency (ROCOF)

This implies that a relay uses the time derivative of frequency to detect islanding. The rate of change of frequency, d_f/d_t will be very high when DG is islanded. At islanding the difference between production and load power is outbalanced with the kinetic energy stored in the turbine and rotor of the machine. This causes a change in the speed which also affects the frequency.

$$ROCOF = \frac{d_f}{d_t} = \frac{\Delta P}{2HG} * f \quad (1)$$

Where,

ΔP = Power mismatch at DG side

H = Moment of inertia for DG system

G = Rated generation capacity of DG

Large systems have large G and H whereas small systems have small G and H . ROCOF relay monitors the voltage waveform and operates if ROCOF is higher than setting for certain duration of time. The setting has to be chosen such that relay triggers for island condition but not for load changes. This method is reliable for large mismatch in power but fails to operate if DG's capacity matches with local loads. An advantage of this method along with rate of change of power is that, even these fail to operate when load matches DG's generation, any local load change would lead to islanding being detected as a result of load and generation mismatch in islanded system. It is clear that the difference between load and production affects the speed derivative. If the production and load are in perfect balance just after a switch to an island operation has occurred the speed derivative will be small and difficult to detect. The grid frequency will not be affected significantly. Hence the ROCOF-relay will not be able to detect the islanding. [13-14]

2.2.1.3. Rate of change of frequency over power (ROCOFOP)

d_f/d_p in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilizes this concept to determine islanding condition. For small power mismatch between DG and local load, rate of change of frequency over power is much more sensitive than rate of frequency over time. [15]

2.2.1.4. Comparison of Rate of Change of Frequency (COROCOF)

COROCOF is based on measuring change of frequency such as ROCOF but at two locations, i.e. main grid and DG side. COROCOF differentiate between rate of change of frequency due to loss of main (LOM) and network perturbations. At main grid the ROCOF is measured and if the value exceeds the limits a block signal will transfer to the DG. At DG side the ROCOF will also be determined. When DG has not received any blocking signal and the value of rate of change of frequency has exceeded the threshold the Relay will send trip. Due to much computational work the practical implementation of this method is very difficult. [7]

2.2.1.5. Rate of Change of Phase Angle Difference (ROCPAD)

ROCPAD method monitors the voltage and current signals at the DG side and estimating the phasors (amplitude, phase and frequency). Then the phase angle difference must be calculated and compared with the threshold. ROCPAD is obtained as follow:

$$ROCPAD = \frac{\Delta(\delta_V - \delta_i)}{\Delta t} \quad (2)$$

Where δ_V and δ_i are voltage and current phase angles. The ROCPAD relay can successfully detect islanding condition even under active power balances in DG. They also have fast response. [4, 16]

2.2.1.6. Voltage Unbalance and Total Harmonic distortion

When islanding occurs, voltage swings occur and there will be voltage unbalance change. Voltage unbalanced (VU) is calculated by the ratio of the negative sequence over the positive sequence.

$$\text{Voltage unbalance} = \frac{V_{\text{negative sequence}}}{V_{\text{positive sequence}}} \quad (3)$$

Because of the voltage swings, there will also be an increased amount of harmonics in the current; the total harmonic distortion can be calculated and used to determine if islanding is occurring. Total harmonic distortion is calculated by taking the geometric sum of the root mean squared (RMS) current of each harmonic component and dividing it by the fundamental RMS current.

$$THD_i = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (4)$$

These methods may not be effective for small changes. As the distribution networks generally include single phase loads, it is highly possible that islanding will change the load balance of DG. Even though the load changes in DG is small, voltage unbalance will occur due to change in network condition. [17]

2.2.1.7. Over /Under Voltage and Under/Over frequency

All grid-connected PV inverters are required to have under/over frequency protection methods (UOF) and under/over voltage protection methods (UOV). These UOF/UOV protective devices protect the customer's equipment and used also as an anti-islanding detection methods. Consider the system configuration shown in Figure (4) in which a photovoltaic panel is connected to the grid. Node 'a' is the point of common coupling between the utility and PV panel. When the utility is connected, real and reactive power ($P_{pv} + jQ_{pv}$) will be supplied from the DG. If the power rating of the load is greater than that of the DG then the power mismatch ΔP , ΔQ will be compensated from the grid. However, when the grid is disconnected and an island is formed, the voltage and frequency will deviate. The behavior of this method will depend on ΔP and ΔQ . If $\Delta P \neq 0$ then the amplitude of the voltage at PCC will change and the UOV protective relay will detect the islanding. Similarly, if $\Delta Q \neq 0$ then the phase of the voltage at the PCC will deviate resulting in frequency deviation which will be detected using UOF protective relays. If ΔP and ΔQ are large enough the voltage and frequency will go beyond the nominal ranges of UOF/UOV protection devices and a trip signal will be sent to trip circuit breaker CB2. This method will fail to detect islanding if the load is closely matched to the inverter's output power so these methods have a large NDZ. The voltage and frequency deviation will not be sufficient to exceed the nominal ranges of UOF/UOV protection devices. [4, 6, 18-19]

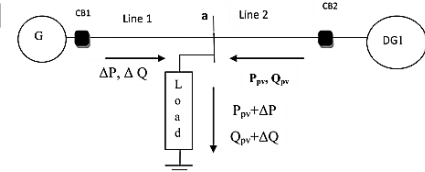


Fig.4. Distribution system with photovoltaic DG

2.2.1.8. Detection of Voltage and/or Current Harmonics

This method of islanding detection is generally applied in conjunction with inverter based technologies when system harmonics are likely to be present. In this method, the island detector measures the total harmonic distortion (THD), sets a threshold and then shuts down when the harmonic distortion exceeds that level. If an assumption is made that a utility-connected system is more “stiff” than a DG-only system, the THD will be less for a utility connected system than for a DG-only connected system. There are several factors that can increase the level of harmonics in a network. Examples include switching power supplies, motor drives, and nonlinear components such as overloaded transformers. The level of harmonics produced by inverters will change between full load and no load conditions. A typical requirement for Inverters is to meet the THD specification of less than 5% under full load conditions. These harmonics are often very small due to the low impedance sink provided by the utility system and the measurability and the threshold setting will exhibit significant issues. This method has found setting thresholds and the ability to accurately measure small harmonics to be very difficult to measure and predict.[17, 20]

2.2.1.9. Phase jump detection

This method involves monitoring the phase difference between the voltage and the current of the DG’s output for a sudden jump. Under normal condition and for current source inverters, the inverter’s output current which will be synchronized with the utility voltage by detecting the rising or falling zero crossing for synchronizing purposes. This can be achieved using a phase locked loop (PLL). In case of islanding, the inverter’s current is fixed by the utility voltage source since it is following the template provided by the PLL but the voltage is no longer fixed. The phase angle of the load should be maintained to that before the disconnection. In order to achieve this condition, the voltage will “jump” to this new phase. The phase error is measured and once it exceeds certain threshold islanding is detected. Figure (5) shows the operation of voltage phase jump detection method.

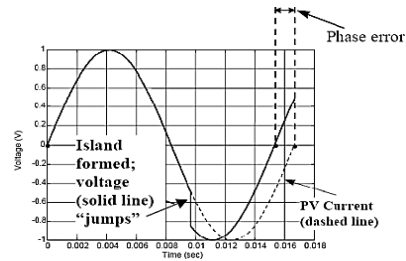


Fig.5. Operation of voltage phase jump detection method

For a current sourced inverter, voltage phase jump detection is determined by measuring the phase difference of the voltage at the point of common coupling and the current through the load. For a voltage sourced inverter, the phase jump detection is determined by measuring the phase difference between the current at the point of common coupling and the voltage at the inverter. It can also be observed that the difference between the voltage phase and current phase at the point of common coupling changes when islanding occurs. This can also be used to determine islanding and can only be used if the load is not purely resistive, which is true in most cases. [9, 12]

2.2.1.10. Rate of Change of Voltage

In this method the usual voltage variations are slow in distribution systems, but if one utility system becomes islanded from the main distribution system, the rate of change of voltage is larger than under regular operation. The non- detection zone of this method is closely coupled with its sensitivity to network disturbances, except in the case of island transitions. [21]

2.2.1.11. Vector Shift (VS)

If the MG becomes islanded, the generator will begin to feed a larger load (or smaller) because the current provided by (or injected into) the power grid is abruptly interrupted. Thus, the generator begins to decelerate (or accelerate). The increase (or decrease) in current changes the DG terminal voltage (V_T). Consequently, the difference between V_T and generator internal voltage (E_1) is suddenly increased (or decreased) and the terminal voltage phasor changes its direction as shown in Figure (6). VS relay is very fast in comparison to other method such as ROCOF but it is sensitive to network faults and it has large NDZ. [16]

2.2.2. Active islanding detection techniques

Active methods can detect islanding in case of perfect matching between generation and load. These

methods depends on perturbing the voltage and current waveforms and then force the system's frequency or voltage at the point of common coupling to deviate outside its acceptable limits then U/OF and U/OV can detect islanding. When the grid is connected this perturbation doesn't affect the system voltage and frequency as the DGs are controlled by the grid. However, when islanding occur the system parameters are affected by this perturbation and then the deviation from its nominal values occur. There are various types of active anti-islanding detection methods discussed as follow:

2.2.2.1. Reactive Power Export Error Detection (RPEED)

This method relies on generating a small amount of reactive power flow by the DG at PCC that is between the DG and the grid or at the location of the RPEED relay. When the grid is connected this power can be maintained in its acceptable level. However, when the grid is disconnected the level of this reactive power flow may exceed its limits. This method has a disadvantage that it is slow and it cannot be used in the system where DG has to generate power at unity power factor. [10]

2.2.2.2. Impedance Measurement

Impedance Measurement attempts to measure the overall impedance of the circuit being fed by the inverter. It does this by slightly "forcing" the current amplitude through the AC cycle, presenting too much current at a given time. Normally this would have no effect on the measured voltage, as the grid is an effectively infinitely stiff voltage source. In the event of a disconnection, even the small forcing would result in a noticeable change in voltage, allowing detection of the island. The main advantage of this method is that it has a vanishingly small NDZ for any given single inverter. However, the inverse is also the main weakness of this method; in the case of multiple inverters, each one would be forcing a slightly different signal into the line, hiding the effects on any one inverter. It is possible to address this problem by communication between the inverters to ensure they all force on the same schedule, but in a non-homogeneous install (multiple installations on a single branch) this becomes difficult or impossible in practice. Additionally, the method only works if the grid is effectively infinite, and in practice many real-world grid connections do not sufficiently meet this criterion. [10, 22-23]

2.2.2.3. Detection of Impedance at Specific Frequency

This method injects a current harmonic of a specific frequency intentionally into PCC. At the disconnection of the grid, if its impedance is much lower than the load impedance at the harmonic frequency, then the harmonic current flows into the grid, and no abnormal voltage is seen. Upon disconnection from the utility, the harmonic current flows into the load. If the local load is linear, then it is possible to inject a harmonic current into PCC. The linear load then produces a harmonic voltage, which can then be detected. The name of this method derives from the fact that the amplitude of the harmonic voltage produced will be proportional to the impedance of the load at the frequency of the harmonic current. [6]

2.2.2.4. Slip-mode Frequency Shift

The perturbation in this method is introduced in the form of phase shift as this method uses positive feedback to change the phase angle of the current waveform at the PCC. When the grid is connected the frequency will be stable and within its limits. However, in the presence of islanding the system frequency is affected by this perturbation and hence it becomes outside its acceptable limits, hence the OFP/UFP trip and the inverter will shut down on a frequency error.

$$i_{inverter} = I_{inverter} \sin(\omega t + \phi) \quad (5)$$

SMS also has the advantages that, it is simple implementation as it only requires a modification to existing components in the inverter filter, small non-detection zones, effective in multiple inverter applications, and it provides a good compromise between islanding detection effectiveness, output power quality, and impact on the transient response of the overall power system. The drawback of this method is that the islanding can go undetected if the slope of the phase of the load is higher than that of the SMS line, as there can be stable operating points within the unstable zone. [6, 23-24]

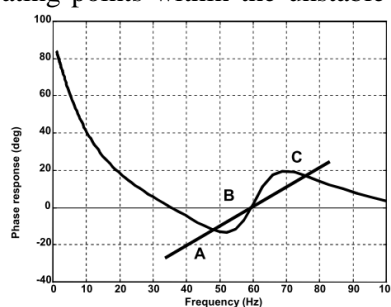


Fig.6. Plot of the current-voltage phase angle vs. frequency characteristic of an inverter utilizing the SMS islanding prevention method

2.2.2.5. Active Frequency Drift (AFD)

This method is based on injection of a slightly distorted current into the PCC. When the grid is connected this distortion doesn't affect the frequency of the system, but when the grid is disconnected this perturbation affect the frequency and hence this change in frequency may force the U/OF to disconnect the DG. Figure (8) shows an example of the distorted DG output current waveform along with undistorted sine waveform for comparison. T_{Vutil} is the period of the utility voltage, $T_{I_{pv}}$ is the period of the sinusoidal portion of the current output of the PV inverter, and t_z is a dead or zero time. The ratio of the zero time t_z to half of the period of the voltage waveform, $T_{Vutil}/2$, is referred to as the "chopping fraction" (C_f):

$$C_f = \frac{2t_z}{T_{Vutil}} \quad (6)$$

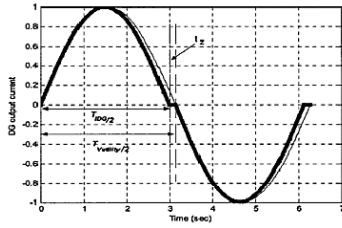


Fig.7. DG output current using AFD

This method has advantage that it is easy to implement with a microprocessor- based controller. However, it intentionally introduces a distortion in the system which will result in power quality degradation. The NDZ of this method depend on the value of chopping fraction used. [15-31]

2.2.2.6. Sandia Frequency Shift (SFS)

This method is an improvement to the AFD method as it applies positive feedback to the frequency at PCC. When the DG is connected to the grid, the presence of a strong utility source doesn't affect the system frequency. However, at the absence of the grid, the frequency error increases, the chopping fraction increases, and the PV inverter also increases its frequency. The inverter thus acts to reinforce the frequency deviation, and this process continues until the frequency reaches the threshold of the OFP. The chopping factor is a

function of the error in the line frequency and may be computed as:

$$C_f = C_{f0} + K_{sfs}(f_a - f_{line}) \quad (7)$$

Where C_{f0} is the chopping factor when there is no frequency error, K_{sfs} is an accelerating gain that does not change direction, f_a is the line frequency measured at PCC, and f_{line} , is the nominal line frequency.

The SFS waveform has either odd or even symmetry; therefore, there will be a phase shift in the fundamental components of this waveform equal to $0.5\omega t_z$. If the zero current segment is small, the higher harmonic components of the current are also small, the SFS current can be approximated by its phase shifted fundamental component. Thus, the angle of the fundamental component of the inverter current varies with the frequency of the PCC and the chopping factor C_f

$$\theta_{SFS}(f) = \frac{\omega t_z}{2} = \pi f t_z = \frac{\pi C_f(f)}{2} \quad (8)$$

This method has the advantage that it is easy to implement and very effective. It has one of the smallest NDZs of all the active anti-islanding detection methods. Also, SFS, like SMS, appears to provide a good compromise between islanding detection effectiveness, output power quality, and system transient response effects. There are some of disadvantages of this method such as SFS requires that the output power quality of the PV inverter be reduced slightly when it is connected to the grid because the positive feedback amplifies changes that take place on the grid. Also, it is possible that the instability in the PV inverter's power output can cause undesirable transient behavior in the system when a weak utility is connected. This problem would grow more severe as the penetration level of PV inverters into the network increased. [32-38]

2.2.2.7. Sandia Voltage Shift

Similarly to Sandia Frequency Shift, Sandia Voltage Shift (SVS) also uses a form of positive feedback to detect islanding. In this case, the inverter decreases its power output and thus its voltage. When the utility is connected, there is little to no change in the output terminal voltage, however when the utility is not connected, the voltage will drop with the reduction of power. The positive feedback control of the voltage reduction is

further accelerated downwards until the under voltage protection relay trips. In micro-controller-based inverters, this method is easy to implement. SVS is commonly implemented simultaneously with SFS, and this combination of methods has been demonstrated to be highly effective in preventing islanding, with an NDZ so small that it is extremely difficult to locate experimentally. The drawback of this method is that it creates a reduction of inverter efficiency. This method may have small impacts on the utility system transient response and power quality. [39-42]

2.2.2.8. Frequency Jump

Frequency Jump (FJ) is also known as the Zebra Method and is a close relative of the Frequency Bias method. In the FJ method, “dead zones” are added similarly to the frequency bias method, but not in every cycle. The frequency is broken into a predefined algorithm, with dead zones added every second or third cycle. When connected to the utility, the inverter only sees a modified current and an unmodified utility linked voltage. When in island state, the voltage and current change as per the inverter programmed wave shape. Therefore, the inverter can detect an island by the modified frequency, or by matching the voltage pattern to the inverter's algorithm. If the pattern is sufficiently sophisticated, FJ can be relatively effective in islanding prevention when used with single inverters. This method is believed to lose effectiveness when used in conjunction with many inverters that use the same algorithm. The primary weakness of the FJ method is that it, like the impedance measurement and frequency bias methods, loses effectiveness in the multiple inverter case unless the dithering of the frequency is somehow synchronized. If not, the variations introduced by the multiple inverters could act to cancel each other out, resulting in detection failure. It is thought that this method should have almost no NDZ in the single-inverter case, due to its similarity to impedance measurement. [6]

2.2.2.9. Mains Monitoring Units with Allocated All-pole Switching Devices Connected in Series (MSD). Also called (ENS).

This method is depends on two independent automatic isolating facility, diverse parallel mains monitoring devices with allocated switching devices connected in series in the external and neutral conductor. This two switching devices in series are

controlled independently. There are some of methods used for islanding detection with this method such as an impedance detection method with additional over/under voltage and frequency trips. These independent units continuously monitor the quality of the connected grid by monitoring voltage, frequency and impedance. The redundant design, as well as an automatic self-test before each connection to the grid, provides an improvement in the reliability of the method. The redundant design and regular self-tests on inverter startup allow the user to install the unit without the need for periodic checks to determine if the anti-islanding circuitry is functional. There are some drawbacks for this method such as for the multiple inverter situations, eventually there will be enough units connected to the same utility branch where their ENS injections will interfere with another or interaction of multiple units causing false trips. [6]

2.2.3. Hybrid detection techniques

These methods apply both active and passive methods for islanding detection. The active methods technique is applied when the islanding is suspected by the passive methods technique. Some of hybrid techniques are discussed as follow:

2.2.3.1. Technique based on positive feedback and voltage unbalance

This method uses the positive feedback method as an active technique combined with voltage unbalance method as a passive technique. Voltage unbalance condition is continuously being determined by monitoring the three phase voltage. In the case of load changing, islanding, switching action, the voltage spikes will be observed. Hence, the voltage unbalance is above its specified limits and the frequency of the DG will be changed. The frequency of the system will changed when the system is islanded. The unbalance can be calculated form this equation, [43]

$$\text{Voltage unbalance} = \frac{V_{\text{negative sequence}}}{V_{\text{positive sequence}}} \quad (9)$$

2.2.3.2. Technique based on Voltage and Reactive Power Shift

In this technique, the variation of voltage over a time is measured to get a covariance value this is represented as passive method which is used to initiate active islanding detection technique. [44]

2.2.3.3. Technique based on voltage and real power shift

This method uses an average rate of change as a passive method and a real power shift as an active method. Islanding detection can be made in this method for multiple DG units operating at a unity power factor by changing the real power of the DG. The active method is applied to detect the islanding when the passive method fails to detect it. [45]

2.2.3.4. Hybrid SFS and Q-f islanding technique

To improve the SFS method, Q-F curve can be used to reduce the NDZ. There are several of optimization methods can be applied to obtain the optimum SFS gain to reduce the NDZ. The q-f droop curve method is then used for the improving of the SFS method. [46-47]

2.2.3.5. Hybrid SMS and Q-f islanding technique

To improve the SMS method, Q-F curve can be used to reduce the NDZ. There are several of optimization methods can be applied to obtain the optimum SMS gain to reduce the NDZ. [48]

2.2.4. Computational intelligence based techniques

There are several types of artificial intelligence methods that can be applied to improve and rapidly detect islanding. In this section, the use of intelligent classifiers is investigated.

2.2.4.1. Artificial neural network (ANN)

ANN has been widely used as a solution for various engineering problems. This method implement the mathematical model instead of a natural neural network in which all useful information and data memory are contained in the brain. An ANN is a network of nodes or neurons analogous to the biological synapse. Multi-layer feed forward networks are widely adopted for power system problems. The system data can be measured to identify any changes in it. The islanding can be detected with a high degree of accuracy and high quality factor of load performance. [49-51]

2.2.4.2. Probabilistic neural network (PNN)

PNN is based on a Bayesian classifier technique that is used in classical pattern recognition

applications. Input, pattern, summation and output layer are the four layers that the PNN is consists of, where each of them has its own function. It is effective and reliable for islanding detection because of the simulation model and real time digital simulator test. [52-53]

2.2.4.3. Artificial immune system (AIS)

AIS can be used for islanding detection that it based on two modules. T-module used to detect the islanding condition. B-module used to improve the detection coverage space. This method is effective in islanding detection. [54-58]

2.2.4.4. Decision trees (DT)

DT was trained in the simulation on a particular pre-fault operating point. It has limitations such as the dependence of the threshold on the splitting criteria and it is a complex task and affects the DT. [59-61]

2.2.4.5. Fuzzy logic (FL)

Fuzzy Logic (FL) has emerged as a promising tool for modeling a system that is not well defined by mathematical formulation. FL represents the expert human knowledge in the form of linguistic variables called fuzzy rules. Fuzzy logic control has also been applied for islanding detection problems. It has some of constraints such as, it is highly abstract, and the heuristic need for experts for rule discovery, lack of self-organization and self-tuning mechanisms that is necessary for the other intelligent methods. [62]

3. Conclusion

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.

4. References

1. IEEE Std. 929-2000, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, Institute of Electrical and Electronics Engineers, Inc., New York, NY.

2. A. Etxegarai, P. Eguía, and I. Zamora, "Analysis of Remote Islanding Detection Methods for Distributed Resources", International Conference on Renewable Energies and Power Quality (ICREPQ'11)13-15 April, Las Palmas de Gran Canaria (Spain), 2011.
3. A. Khamis, H. Shareef, E. Bizkevelci, and T. Khatib, "A review of islanding detection techniques for renewable distributed generation systems", *Renewable and Sustainable Energy Reviews*, Vol. 28, pp. 483–493, 2013.
4. A. Samui and S. Samantaray, "Assessment of ROCPAD Relay for Islanding Detection in Distributed Generation", *IEEE transactions on Power Systems*, Vol.2, Issue No. 2, 391-398, June 2011.
5. E. Schweitzer et al., "Synchrophasor-Based Power System Protection and Control Applications", *Modern Electric Power Systems* 2010.
6. W. Bower and M. Ropp, "Evaluation of Islanding Detection Methods for Photovoltaic Utility-Interactive Power Systems", *Photovoltaic Systems Research and Development*, Sandia National Laboratories IEA-PVPS T5-09: 2002, March 2002.
7. M. Redfern, J. Barren, O. Usta, "A new microprocessor based islanding protection algorithm for dispersed storage and generation units", *IEEE Trans. Power Del.*, vol. 10, no. 3, (1995), pp. 1249-1254.
8. R. Kunte, G. Wenzhong, "Comparison and review of islanding detection techniques for distributed energy resources", *Proceedings of the 40th, 08 North American Power Symposium, NAPS; 2008*. p. 1–8.
9. A. Llaría, O. Curea, J. Jimenez, H. Camblong, "Survey on Microgrids: unplanned islanding and related inverter control techniques", *Renewable Energy* 2011; 36:2052–61.
10. H. Mohamad, H. Mokhlis, A. Bakar, H. Ping, "A review on islanding operation and control for distribution network connected with small hydro power plant", *Renewable and Sustainable Energy Reviews* 2011; 15:395262.
11. W. Xu, G. Zhang, C. Li, W. Wang, G. Wang, J. Kliber, "A power line signaling based technique for anti-islanding protection of distributed generators - part I: scheme and analysis", *IEEE Transaction on Power Delivery* July, 2007;22(3): 1758–66.
12. B. Yu, M. Matsui, G. Yu, "A review of current anti-islanding methods for photovoltaic power system", *Solar Energy* 2010; 84:745–54.
13. W. Freitas, X. Wilsun, C. Affonso, H. Zhenyu, "Comparative analysis between ROCOF and vector surge relays for distributed generation applications", *IEEE Transactions on Power Delivery* 2005; 20:1315–24.
14. P. Mahat "Control and Operation of Islanded Distribution System" *Proceedings 2010 Denmark PhD, Alaborg university*, pp1-28, Sep.2010.
15. Robitaille M., Agbossou K., Doumbia M.L., "Modeling of an islanding protection method for a hybrid renewable distributed generator", *Electr. Comput. Eng.*, 2005, 1, pp. 1477–1481.
16. M. Vatani, T. Amrall, I. Soltan "Comparative of Islanding Detection Passive methods for Distributed Generation Application" *International Journal of innovation & Scientific Research* 2351-8014Vol.8 No.2,pp.234- 241, Sep 2014.
17. S. Jang, and K. Kim, "An islanding detection method for distributed generations using voltage unbalance and total harmonic distortion of current," *IEEE Tran. Power Delivery*, vol. 19, no. 2, pp. 745-752, April 2004.
18. K. Ebadollah, and S. Javad, "Islanding detection method for photovoltaic distributed generation based on voltage drifting", *IET Generation, Transmission & Distribution*, Vol. 7, No. 6, pp. 584–592, 2013.
19. K. Jia, T. Bi, B. Liu, D. Thomas, and A. Goodman, "Advanced islanding detection utilized in distribution systems with DFIG", *International Journal of Electrical Power & Energy Systems* Vol. 63, pp. 113–123, 2014.
20. F. Mango, M. Liserre, A. Aquila, A. Pigazo, "Overview of anti-islanding algorithms for PV systems. Part I: Passive methods" 12th international power electronics and motion control conference, 2006, EPE-PEMC 2006. August 30, 2006–September 1, 2006. p. 1878–83.
21. J. Kim, J. Kim, Y. Ji, Y. Jung, and C. Won "An Islanding Detection method for a Grid-connected System Based on the Goertzel Algorithm" *IEEE Trans. On Power Electronics*, Vol.26, No.4,pp.1049-1055, April 2011
22. P. Mahat, Z. Chen, B. Jensen, "Review on islanding operation of distribution system with distributed generation" *Power and energy society general meeting; 2011*. p. 1–8.
23. N. Boonyapakdee, T. Sapaklom, and M. Konghirum "An Implement of Improved Combine Active Islanding Detection Method on frequency and phase perturbations", *IEEE International Conference on Electrical Machines and System*, pp208- 2013, Oct 2013.
24. F. Liu, Y. Kang, Y. Zhang, S. Duan, X. Lin "Improved SMS Islanding Detection Method for Grid-Connected Converters", *Renewable Power Generation, IET* Vol:4, No: 1, pp. 36 – 42, January 2010.
25. A. Yafaoui, B. Wu, S. Kouro, "Improved active frequency drift anti-islanding detection method for grid connected photovoltaic systems" *IEEE Transaction on Power Electronics* 2012;27:2367–75.
26. L. Lopes, H. Sun, "Performance assessment of active frequency drifting islanding detection methods", *IEEE Transactions on Energy Conversion* 2006; 21(March (1)):171–80.
27. F. Liu, Y. Kang and 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.
28. L. PhaniRaghav, T. Sandhya, "An Active Frequency Drift Method for an Islanding Detection of Grid Connected Microturbine Generation System", *International Journal of Innovative Research in Science, Engineering and Technology- (ICETS'14)*, Vol 3, Special Issue 1, February 2014.
29. A. Yafaoui, B. Wu, and S. Kouro, "Improved Active Frequency Drift Anti-islanding Detection Method for Grid Connected Photovoltaic Systems", *IEEE Transaction on Power Electronics*, Vol. 27, No. 5, May 2012.
30. A. Yafaoui, B. Wu and S. Kouro, "Improved Active Frequency Drift Anti-islanding Method with Lower Total Harmonic Distortion", *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society*, pp. 3216 – 3221, 2010 IEEE.
31. W. Huang, T. Zheng, F. Yuan, Z. Wang, S. Xu, "Analysis of the NDZ Formulation Theory of Active Frequency Shift Islanding Detection Method for Grid Connected PV System", *IEEE Power and Energy Engineering Conference (APPEEC), PES Asia-Pacific*, pp. 1 – 5, 2013.

32. C. Yoo, D. Jang, S. Han, D. Oh, S. Hong, "A new phase drift anti-islanding method for grid-connected inverter system", Eighth international conference on power electronics - ECCE Asia; 2011. p. 902–906.
33. W. Teoh, C. Tan, "An overview of islanding detection methods in photovoltaic systems", World Academy of Science Engineering and Technology 2011:674–82.
34. H. Zeineldin, S. Conti, "Sandia frequency shift parameter selection for multi-inverter systems to eliminate non-detection zone", Renewable Power Generation, IET 2011; 5:175–83.
35. H. Vahedi, and M. Karrari, "Adaptive Fuzzy Sandia Frequency Shift Method for Islanding Protection of Inverter Based Distributed Generation", IEEE Transaction on Power Delivery, Vol. 28, No. 1, January 2013.
36. P. Du, Z. Ye, E. Aponte, J. Keith, and L. Fan, "Positive-Feedback-Based Active Anti-Islanding Schemes for Inverter-Based Distributed Generators: Basic Principle, Design Guideline and Performance Analysis", IEEE Transaction on Power Electronics, vol. 25, no. 12, pp. 2941–2948, Dec. 2010.
37. X. Wang, W. Freitas, and W. Xu, "Dynamic Non-Detection Zones of Positive Feedback Anti-Islanding Methods for Inverter-Based Distributed Generators", IEEE Transaction on Power Delivery, Vol. 26, No. 2, pp. 1145–1155 April 2011
38. H. Zeineldin, and M. Salama, "Impact of load frequency dependence on the NDZ and performance of the SFS islanding detection method", IEEE Transactions Industrial Electronics, Vol. 58, No. 1, pp. 139–146, 2011.
39. B. Bahrani, H. Karimi, R. Iravani, "Nondetection zone assessment of an active islanding detection method and its experimental evaluation", IEEE Transactions on Power Delivery 2011; 26:517–25.
40. D. Velasco, C. Trujillo, G. Garcerá and E. Figueres, "Review of Anti-Islanding Techniques in Distributed Generators", Renewable and Sustainable Energy Reviews, 14 (2010) 1608–1614.
41. B. Rani, M. Srikanth, G. Ilango, and C. Nagamani, "An active islanding detection technique for current controlled inverter", Renewable Energy, Vol. 51, pp. 189–196, 2013.
42. B. Álvarez, O. Rivera, "Survey of distributed generation islanding detection methods". Latin America Transactions, IEEE (Revista IEEE America Latina), Vol. 8, No. 5, pp. 565 – 570, 2010.
43. V. Menon, M. Nehrir, "A hybrid islanding detection technique using voltage unbalance and frequency set point" IEEE Transactions on Power Systems February, 2007; 22(1):442–8.
44. J. Yin, L. Chang, and C. Diduch, "A new hybrid anti-islanding algorithm in grid connected three-phase inverter system", 2006 IEEE Power Electronics Specialists Conference, pp. 1-7.
45. Chang, WA. "Hybrid islanding detection method for distributed synchronous generators", the 2010 international power electronics conference; 2010. p. 1326–1330.
46. H. Vahedi, R. Noroozian, A. Jalilvand, G. Gharehpetian, "Hybrid SFS and Q-f islanding detection method for inverter-based DG" IEEE international conference on power and energy (PECon2010); 2010. p. 672–676.
47. G. Bayrak, and M. Cebeci, "A novel anti islanding detection method for grid connected fuel cell power generation systems", International Journal of Hydrogen Energy, Vol. 39, No.16, pp. 8872–8880, 2014.
48. S. Akhlaghi, A. Ghadimi, and A. Akhlaghi, "A novel hybrid islanding detection method combination of SMS and Q-f for islanding detection of inverter-based DG", Power and energy conference at Illinois (PECI), 2014, pp. 1–8.
49. R. Irani, R. Nasimi, "Application of artificial bee colony-based neural network in bottom hole pressure prediction in underbalanced drilling", Journal of Petroleum Science and Engineering 2011; 78:6–12.
50. M. Oliveira, J. Almeida, "Application of artificial intelligence techniques in modeling and control of a nuclear power plant pressurizer system", Progress in Nuclear Energy 2013; 63:71–85.
51. R. Pahlavan, M. Omid, A. Akram, "Energy input–output analysis and application of artificial neural networks for predicting greenhouse basil production", Energy 2012; 37:171–6.
52. S. Samantaray, B. Babu, P. Dash, "Probabilistic neural network based islanding detection in distributed generation", Electric Power Components and Systems 2011;39:191–203.
53. W. Najy, H. Zeineldin, A. Alaboudy, W. Woon, "A bayesian passive islanding detection method for inverter-based distributed generation using ESPRIT", IEEE Transactions on Power Delivery 2011;26:2687–96.
54. L. de Castro and F. Von Zuben. "Learning and Optimization Using the Clonal Selection Principle", IEEE Transactions on Evolutionary Computation, Special Issue on Artificial Immune Systems, 6(3), pp. 239–251, 2001.
55. L. de Castro and F. Von Zuben, "Artificial Immune System: Part 1 – Basic Theory and Applications", Technical report, Dec 1999.
56. D. Dasgupta and N. Okine, "Immunity-Based Systems: A Survey", In Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Oct 1997.
57. L. de Castro and J. Timmis, "Artificial Immune Systems : A Novel paradigm to Pattern Recognition", In Artificial Neural Networks in Pattern Recognition, SOCO-2002, University of Paisley, UK, 2002.
58. X. Wang, J. Cheng, Z. Yin, M. Guo, "A new approach of obtaining reservoir operation rules: Artificial immune recognition system", Expert Systems with Applications 38 (2011) 11701–11707.
59. X. Lin, X. Dong, Y. Lu, "Application of intelligent algorithm in island detection of distributed generation", Transmission and distribution conference and exposition (IEEE PES); 2010. p. 1–7.
60. M. Thomas, P. Terang, "Islanding detection using decision tree approach. Power Electronics", Drives and Energy Systems (PEDES) 2010:1–6.
61. R. Sun, Z. Wu, V. Centeno, "Power system islanding detection & identification using topology approach and decision tree", 2011 IEEE power and energy society general meeting; 2011. p. 1–6.
62. S. Samantaray, K. El-arroudi, G. Joós, I. Kamwa, "A fuzzy rule-based approach for islanding detection in distributed generation", IEEE Transaction on Power Delivery 2010; 25:1427–33.