AN ASSESSMENT OF DISTRIBUTED GENERATION ISLANDING DETECTION METHODS

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ABSTRACT

The advancement in new technology like fuel cell, wind turbine, customer demands for better power quality and reliability are forcing the power industry to shift for distributed generations. Hence distributed generation (DG) has recently gained a lot of momentum in the power industry due to market deregulations and environmental concerns. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system yet continues to be energized by distributed generators. An important requirement to interconnect a DG to power distributed system is the capability of the DG to detect islanding detection. Failure to trip islanded generators can lead to a number of problems to the generators and the connected loads. Typically, a distributed generator should be disconnected within 100 to 300 ms after loss of main supply. To achieve such a goal, each distributed generator must be equipped with an islanding detection device, which is also called anti islanding devices. This paper discusses the relevant issues and aims regarding existing techniques used for islanding detection.

KEYWORDS: *Islanding detection, distributed generation, remote techniques, interconnected system, non detection zone etc.*

I. INTRODUCTION

These days, electric power utilities are concerned with distributed generators including photovoltaic, wind farm, fuel cells, micro-sized turbine, and internal combustion engine generators as many good alternatives to solve environmental problems and to cope with rising energy prices and power plant construction costs. Distributed generation (DG) may make a contribution to improve quality of power, minimize peak loads and eliminate the need for reserve margin [1], [2]. Most DGs may be connected in parallel and supply power into power grids as well as local loads. Therefore, DG must be operated in such an inherently safe manner that DG should supply the generated power to the network loads only if the utility power supply is present. If DG is feeding the power to the networks without the utility supply, then it produces several negative impacts on utility power system and the DG itself, such as the safety hazards to utility personnel and the public, the quality problems of electric service to the utility customers, and serious damages to the DG if utility power is wrongly restored [2], [3].Therefore, during the interruptions of utility power, the connected DG must detect the loss of utility power and disconnect itself from Power grid as soon as possible. This paper deals with a particular problem that occurs at the interface between a distributed generation plant and the rest of the power system. The problem can be described as islanding detection in power systems. The problem has been investigated and discussed extensively in the last few years.

Recent interest in distributed generator installation into low voltage busses near electrical consumers has created some new challenges for protection engineers that are different from traditional radially based protection methodologies. This paper includes detail study of different existing techniques used for islanding detection of distributed generation which are broadly classified in remote detection techniques and local detection techniques

II. ISLANDING

Islanding is the situation in which a distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by DG connected to it. As shown in the figure1. Traditionally, a distribution system doesn't have any active power generating source in it and it doesn't get power in case of a fault in transmission line upstream but with DG, this presumption is no longer valid. Current practice is that almost all utilities require DG to be disconnected from the grid as soon as possible in case of islanding. IEEE 929-1988 standard [3] requires the disconnection of DG once it is islanded .Islanding can be intentional or Non intentional. During maintenance service on the utility grid, the shutdown of the utility grid may cause islanding of generators. As the loss of the grid is voluntary the islanding is known. Non-intentional islanding, caused by accidental shut down of the grid is of more interest. As there are various issues with unintentional islanding. IEEE 1547-2003 standard [4] stipulates a maximum delay of 2 seconds for detection of an unintentional island and all DGs ceasing to energize the distribution system,

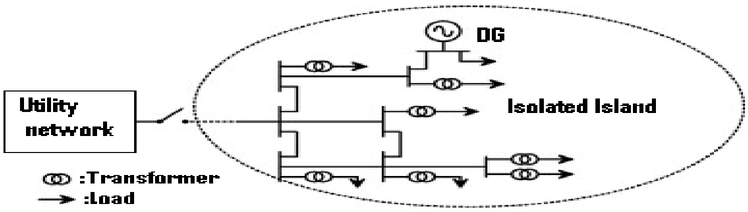

Figure 1. Scenario of islanding operation

2.1 Issues with Islanding

Although there are some benefits of islanding operation there are some drawbacks as well. Some of them are as follows:

- Line worker safety can be threatened by DG sources feeding a system after primary sources have been opened and tagged out.
- The voltage and frequency may not be maintained within a standard permissible level. Islanded system may be inadequately grounded by the DG interconnection.
- Instantaneous reclosing could result in out of phase reclosing of DG. As a result of which large mechanical torques and currents are created that can damage the generators or prime movers [5] Also, transients are created, which are potentially damaging to utility and other customer equipment. Out of phase reclosing, if occurs at a voltage peak, will generate a very severe capacitive switching transient and in a lightly damped system, the crest over-voltage can approach three times rated voltage [6].
- Various risks resulting from this include the degradation of the electric components as a consequence of voltage& frequency drifts. Due to these reasons, it is very important to detect the islanding quickly and accurately.

III. REVIEW OF ISLANDING DETECTION TECHNIQUES

The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and/ and decide whether or not an islanding situation has occurred from change in these parameters. Islanding detection techniques can be divided into remote and local techniques and local techniques can further be divided into passive, active and hybrid techniques as shown in Figure 2.

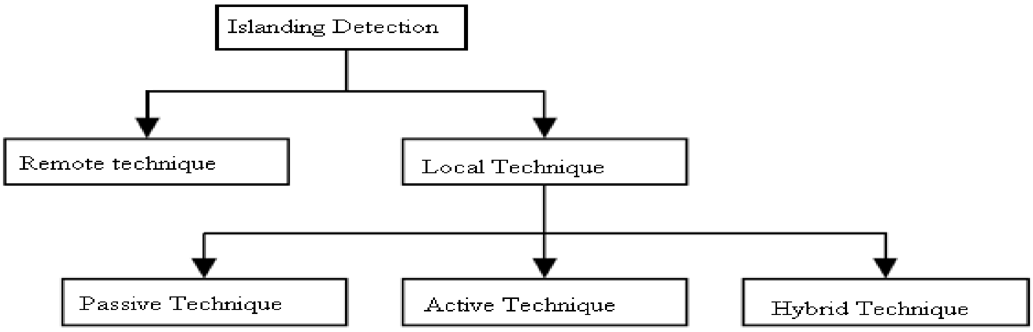

Figure 2. Islanding detection techniques

3.1 Remote Islanding Detection Techniques

Remote islanding detection techniques are based on communication between utilities and DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical .Some of the remote islanding detection techniques are as follows:

3.1.1 Power Line Signaling Scheme

These methods use the power line as a carrier of signals to transmit islanded or non-islanded information on the power lines. The apparatus includes a signal generator at the substation (25+ kV) that is coupled into the network where it continually broadcasts a signal as shown in figure 3. Due to the low-pass filter nature of a power system, the signals need to be transmitted near or below the fundamental frequency and not interfere with other carrier technologies such as automatic meter reading. Each DG is then equipped with a signal detector to receive this transmitted signal. Under normal operating conditions, the signal is received by the DG and the system remains connected. However, if an island state occurs, the transmitted signal is cut off because of the substation breaker opening and the signal can not be received by the DG, hence indicating an island condition.

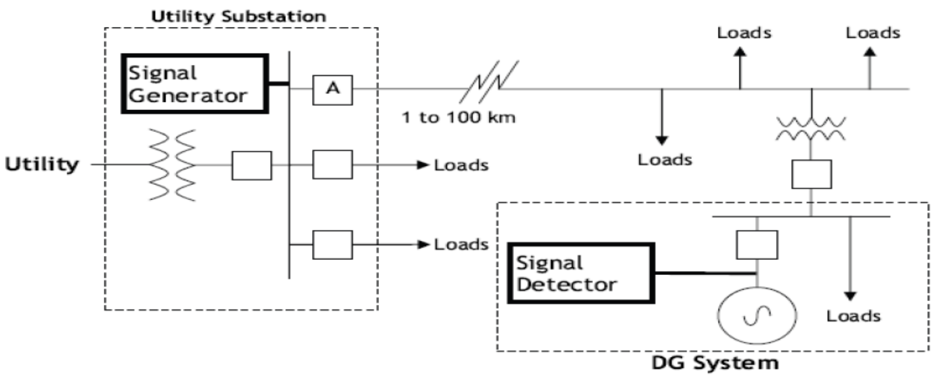

Figure 3. Distributed Generation power line Signaling Islanding Detection

This method has the advantages of its simplicity of control and its reliability. In a radial system there is only one transmitting generator needed that can continuously relay a message to many DGs in the network. The only times the message is not received is if the interconnecting breaker has been opened, or if there is a line fault that corrupts the transmitted signal.

There are also several significant disadvantages to this method, the fist being the practical implementation. To connect the device to a substation, a high voltage to low voltage coupling transformer is required. A transformer of this voltage capacity can have prohibitive cost barriers associated with it that may be especially undesirable for the first DG system installed in the local network. Another disadvantage is if the signaling method is applied in a non radial system, resulting in the use of multiple signal generators. This scenario can be seen in Figure 4.where the three feeder busses connect to one island bus. The implementation of this system, opposed to a simple radial system, will be up to three times the cost.

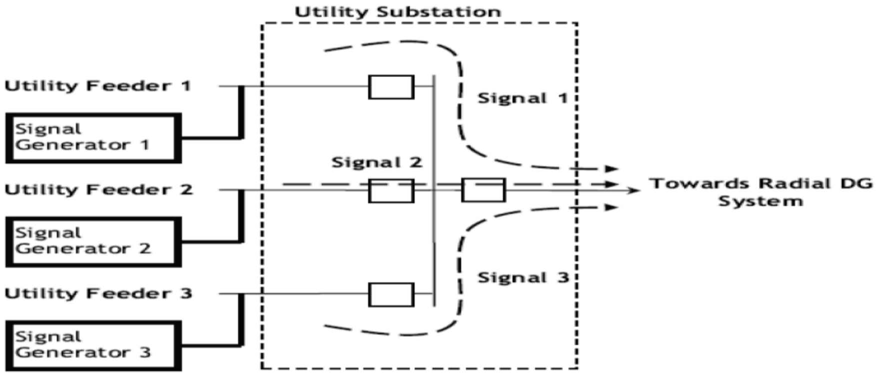

Figure 4. Distributed Generation Multi Power Line Signaling Islanding Detection Issue

Another problem for power line communication is the complexity of the network and the affected networks. A perfectly radial network with one connecting breaker is a simple example of island signaling; however, more complex systems with multiple utility feeders may find that differentiation between upstream breakers difficult.

3.1.2 Transfer Trip Scheme

The basic idea of transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system. Supervisory Control and Data Acquisition (SCADA) systems can be used for that. When a disconnection is detected at the substation, the transfer trip system determines which areas are islanded and sends the appropriate signal to the DGs, to either remain in operation, or to discontinue operation. Transfer tip has the distinct advantage similar to Power Line Carrier Signal that it is a very simple concept. With a radial topology that has few DG sources and a limited number of breakers, the system state can be sent to the DG directly from each monitoring point. This is one of the most common schemes used for islanding detection [7].This can be seen in figure 5.

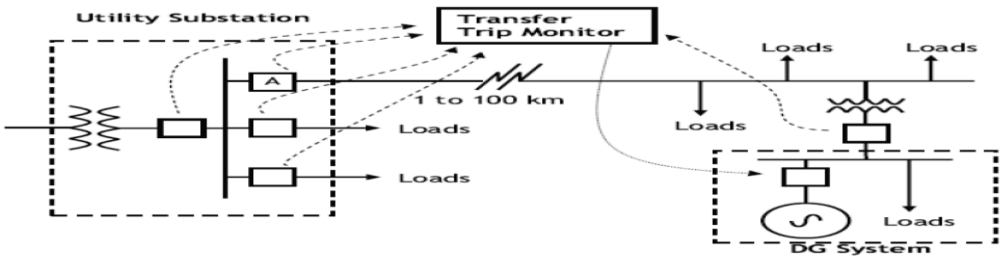

Figure 5. Distributed Generation Transfer Trip Islanding Detection

The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating. Reconfiguration of this device in the planning stages of DG network is necessary in order to consider if the network is expected to grow or if many DG installations are planned. The other weakness of this system is control. As the substation gains control of the DG, the DG may lose control over power producing capability and special agreements may be necessary with the utility. If the transfer trip method is implemented correctly in a simple network, there are no non-detection zones of operation.

3.2 Local Detection Techniques

It is based on the measurement of system parameters at the DG site, like voltage, frequency, etc. It is further classified as:

3.2.1 Passive Detection Techniques

Passive methods work on measuring system parameters such as variations in voltage, frequency, harmonic distortion, etc. These parameters vary greatly when the system is islanded. Differentiation between an islanding and grid connected condition is based upon the thresholds set for these parameters. Special care should be taken while setting the threshold value so as to differentiate islanding from other disturbances in the system. Passive techniques are fast and they don't introduce disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition.

There are various passive islanding detection techniques and some of them are as follows:

(a) Rate of change of output power: The rate of change of output power, , at the DG side, once it is islanded, will be much greater than that of the rate of change of output power before the DG is islanded for the same rate of load change[8]. It has been found that this method is much more effective when dp/dt

the distribution system with DG has unbalanced load rather than balanced load. [9]

(b) Rate of change of frequency: The rate of change of frequency, df/dt, will be very high when the DG is islanded. The rate of change of frequency (ROCOF) can be given by equation (1). [10]

$$ROCOF, \frac{df}{dt} = \frac{\Delta P}{2HG} \times f \quad (1)$$

Where, ΔP is power mismatch at the DG side

H is the moment of inertia for DG/system

G is the rated generation capacity of the DG/system

Large systems have large H and G where as small systems have small H and G giving larger value for *df/dt* ROCOF relay monitors the voltage waveform and will Operate if ROCOF is higher than setting for certain duration of time. The setting has to be chosen in such a way that the relay will trigger for island condition but not for load changes. This method is highly reliable when there is large mismatch in power but it fails to operate if DG's capacity matches with its local loads. However, an advantage of this method along with the rate of change of power algorithm is that, even they fail to operate when load matches DG's generation, any subsequent local load change would generally lead to islanding being detected as a result of load and generation mismatch in the islanded system.

(c) Rate of change of frequency over power: *df/dp* in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilize this concept to determine islanding condition .Furthermore, test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of frequency over time [11].

(d) Voltage unbalance: Once the islanding occurs, DG has to take change of the loads in the island. If the change in loading is large, then islanding conditions are easily detected by monitoring several parameters: voltage magnitude, phase displacement, and frequency change. However, these methods may not be effective if the changes are small. As the distribution networks generally include single-phase loads, it is highly possible that the islanding will change the load balance of DG. Furthermore, even though the change in DG loads is small, voltage unbalance will occur due to the change in network condition. [12-13]

(e) Harmonic distortion: Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has inverter based DGs. One approach to detect islanding is to monitor the change of total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed **[**14].The change in the third harmonic of the DG's voltage also gives a good picture of when the DG is islanded.

3.2.2. Active Detection Techniques

With active methods, islanding can be detected even under the perfect match of generation and load, which is not possible in case of the passive detection schemes. Active methods directly interact with the power system operation by introducing perturbations. The idea of an active detection method is that this small perturbation will result in a significant change in system parameters when the DG is islanded, whereas the change will be negligible when the DG is connected to the grid.

(a) Reactive power export error detection: In this scheme, DG generates a level of reactive power flow at the point of common coupling (PCC) between the DG site and grid [15] or at the point where the Reed relay is connected [16]. This power flow can only be maintained when the grid is connected. Islanding can be detected if the level of reactive power flow is not maintained at the set value. For the synchronous generator based DG, islanding can be detected by increasing the internal induced voltage of DG by a small amount from time to time and monitoring the change in voltage and reactive power at the terminal where DG is connected to the distribution system. A large change in the terminal voltage, with the reactive power remaining almost unchanged, indicates islanding. [17]The major drawbacks of this method are it is slow and it cannot be used in the system where DG has to generate power at unity power factor.

(b) Phase (or frequency) shift methods: Measurement of the relative phase shift can give a good idea of when the inverter based DG is islanded. A small perturbation is introduced in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. The Slip-Mode Frequency Shift Algorithm (SMS) [18] uses positive feedback which changes phase angle of the current of the inverter with respect to the deviation of frequency at the PCC. A SMS curve is given by the equation (2).

$$\theta = \theta_m \, sin\left(\frac{\pi}{2} \frac{f^{(k-1)} - f_n}{f_m - f_n}\right) \quad (2)$$

Where θ_m is the maximum phase shift that occurs at frequency f_m. f_n is the nominal frequency and $f^{(k-1)}$ is the frequency at previous cycle. A SMS curve is designed in such a way that its slope is greater than that of the phase of the load in the unstable region. A SMS curve, with θm =10° and fm = 53 Hz, is shown in Figure 6. When the utility is disconnected, operation will move through the unstable region towards a stable operating point (denoted by black dots in Figure 6. Islanding is detected when the inverter frequency exceeds the setting.

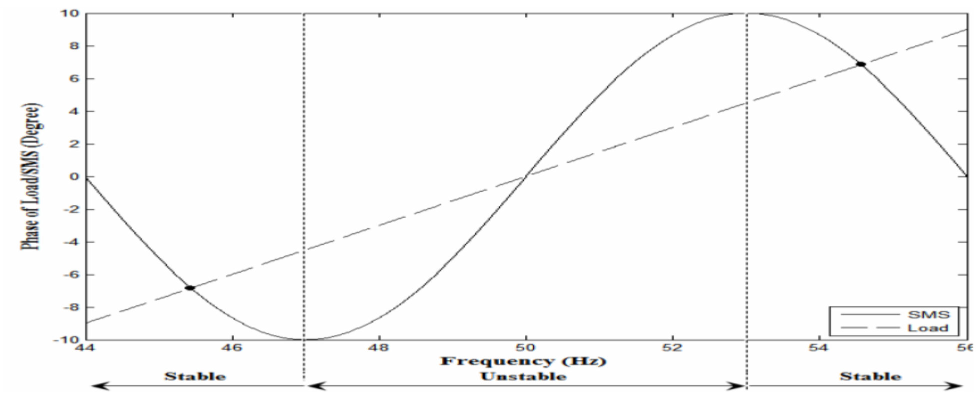

Figure 6. Phase response of DG and local load

This detection scheme can be used in a system with more than one inverter based DG. 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 [19].

3.3 Hybrid Detection Schemes

Hybrid methods employ both the active and passive detection techniques. The active technique is implemented only when the islanding is suspected by the passive technique. Some of the hybrid techniques are discussed as follows:

(a) Technique based on positive feedback (PF) and voltage imbalance (VU): This islanding detection technique uses the PF (active technique) and *VU* (passive technique). The main idea is to monitor the three-phase voltages continuously to determinate *VU* [20] which is given by equation (3).

$$VU = \frac{v_{+sq}}{v_{-sq}} \quad (3)$$

V_{+Sq} and V_{-Sq} are the positive and negative sequence voltages, respectively. Voltage spikes will be observed for load change, islanding, switching action, etc. Whenever a *VU* spike is above the set value, frequency set point of the DG is changed. The system frequency will change if the system is islanded.

(b) Technique based on voltage and reactive power shift:
In this technique voltage variation over a time is measured to get a covariance value (passive) which is used to initiate an active islanding detection technique, adaptive reactive power shift (ARPS) algorithm given by equation(4).[21].

$$\mathrm{Co-variance}(\mathrm{T_{av\prime}}, \mathrm{T_v}) = \mathrm{E}\ \ \mathrm{T_{av\prime}^{(n)}} - \mathrm{U_{AV}}\ \ \mathrm{T_v^{(n)}} - \mathrm{U_v} \tag{4}$$

T_{av}' is the average of the previous four voltage periods, U_{av} is the mean of T_{av}', T_v is the voltage periods,
U_V is the mean of T_V
The ARPS uses the same mechanism as ALPS, except it uses the d-axis current shift instead of current phase shift. The d-axis current shift, i_d^k or reactive power shift is given by equation (5).

$$i_d^k = K_d \left(\frac{\mathrm{Tav}' - \mathrm{T_v^{(k)}}}{\mathrm{T_v^{(k)}}} \right) \tag{5}$$

K_d is chosen such that the d-axis current variation is less than 1 percent of q-axis current in inverter's normal operation. The additional d-axis current, after the suspicion of island, would accelerates the phase shift action, which leads to a fast frequency shift when the DG is islanded. There is no single islanding detection technique which will work satisfactorily for all systems under all situations. The choice of the islanding detection technique will largely depend on the type of the DG and system characteristics. Recently, hybrid detection techniques have been proposed and it seems that the hybrid detection technique is the way to go with passive technique detecting the islanding when change in system parameter is large and initiating the active technique when the change in system parameter is not so large for the passive technique to have an absolute discrimination.

IV. COMPARISONS OF ISLANDING DETECTION TECHNIQUES

Table 1. Comparisons of Islanding Detection Techniques.

Islanding Detection Techniques	Advantages	Disadvantages	Examples
Remote Techniques	Highly Reliable	Expensive to implement specially for small system	• Transfer trip scheme • Power line signaling scheme
Local Techniques a) Passive Techniques	• Short detection time • Do not perturb the system • Accurate when there is a large mismatch in generation and demand in the islanded system.	• Difficult to detect islanding when the load and generation in the islanded system closely match • Special care has to be taken while setting the thresholds • If the setting is too aggressive then it could result in nuisance tripping	• Rate of change of output power scheme • Rate of change of frequency scheme • Rate of change of frequency over power scheme • Change of impedance scheme • Voltage unbalance scheme • Harmonic distortion scheme
b) Active techniques	• Can detect islanding even in a perfect match between generation and demand in the islanded system (Small NDZ	• Introduce perturbation in the system • Detection time is slow as a result of extra time needed to see the system response for perturbation • Perturbation often degrades the power quantity and if significant enough, it may degrade the system stability even when connected to the	• Reactive power export error detection scheme • Impedance measurement scheme • Phase (or frequency) shift schemes (like SMS, AFD, AFDPF and ALPS

		grid	
c) Hybrid Techniques	• Have small NDZ. • Perturbation is introduced only when islanding is suspected.	• Islanding detection time is prolonged as both passive and active technique is implemented	• Technique based on positive feedback and voltage imbalance • Technique based on voltage and reactive power shift.

V. CONCLUSION

This paper describes and compares different islanding detection techniques. Fast and accurate detection of islanding is one of the major challenges in today's power system with many distribution systems already having significant penetration of DG as there are few issues yet to be resolved with islanding. Islanding detection is also important as islanding operation of distributed system is seen a viable option in the future to improve the reliability and quality of the supply.

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