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REVIEW OF ISLANDING DETECTION METHODS FOR DISTRIBUTED GENERATION

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***Abstract*:**. This paper presents an overview of power system islanding and islanding detection techniques. Islanding detection techniques, for a distribution system with distributed generation (DG), can broadly be divided into remote and local techniques. A remote islanding detection technique is associated with islanding detection on the utility side, whereas a local technique is associated with islanding detection on the DG side. Local techniques can further be divided into passive techniques, active techniques and hybrid techniques. These islanding detection techniques for DG are described and analyzed.

Index Terms-- Distributed generation, islanding detection.

I. Introduction:

To meet the energy consumption demand of the world, all are looking towards the renewable DG. The research on the growth of DG systems and their utilization is increasing around the world because of their advantages and low pollution compared to the burning of fossil fuels. In the conventional power system, the power is received by the consumers, but in the DG connected smart grid, consumers can also produce the power. The small scale power generation systems such as photo voltaic, mini hydro, tidal, biomass connected to the grid at the consumer level are called DG.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. Islanding can either be intentional or unintentional. Intentional islanding is a purposeful isolation of a proportion of the grid during fault or disturbance in which can be designed to assist continuity supplying electrical energy to the load demand. In contrast, unintentional islanding is an uncontrollable operation which brings serious danger to the utility workers as well as the DG units in the island. The concern is mainly in regards to the fluctuation and variation of the voltage and frequency. Stability interference of the systems might cause complication for proper automatic grid reconnection and restoration [2]. Islanding causes the following adversities in a power system.

II. Need of Islanding Detection

- Fatal accidents may occur when some workers may not know that the system is still alive even after the grid supply has been disconnected.
- The system may be subjected to abnormal voltage and frequency fluctuations
- Degradation of power quality
- Grid protection interference.
- Out of phase reclosing.
- Equipment damage.
- Load vs. generation imbalance may occur in the system

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.

• The 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 [4]. 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 [5]. Due to these reasons, it is very important to detect the islanding quickly and accurately.

III. Islanding Methodology

Islanding is the situation in which a distribution system becomes electrically isolated from the rest of the power system, yet continues to be energized by Distributed Generator (DG) connected to it. As shown in the Figure 1. Usually, 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, 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 concern. As there are various issues with unintentional islanding.

Island mode operation relates to those power plants that operate in isolation from the national or local electricity distribution network. Generators connected to the electricity grid in parallel mode, which can generate independently in the event of a grid power supply failure. A common example of Islanding is a distribution feeder that has solar panels attached to it. Island mode operation relates to power plants that operate in isolation from the national or local electricity distribution network. Generators connected to the electricity grid in. The parallel mode, can generate power independently in the event of a grid power outage

One of the most important problems to fix is related with the potential generation of islands. Figure 1 illustrates the situation of islanding. if the EPS fails and the DG keeps on working in normal operation, energizing distribution lines and local loads connected to it, an electric isolated island is formed. This problem, known as islanding operation, is to be avoided since it could involve important and serious consequences from the EPS side, security measures have to be adopted in order to ensure the safety of the personnel working on the utility along with the guarantee the reliability of the utility grid .Islanding may occur because of the following conditions:

- At the utility end, some fault is detected and a disconnecting device operates, but it is not detected by the PV inverter or protection devices.
- Equipment failure may cause accidental opening of the normal utility supply.
- Intentional disconnect for servicing either at a point on the utility or at the service entrance.
- Human error or malicious mischief/sabotage.
- An Act of Nature[16]

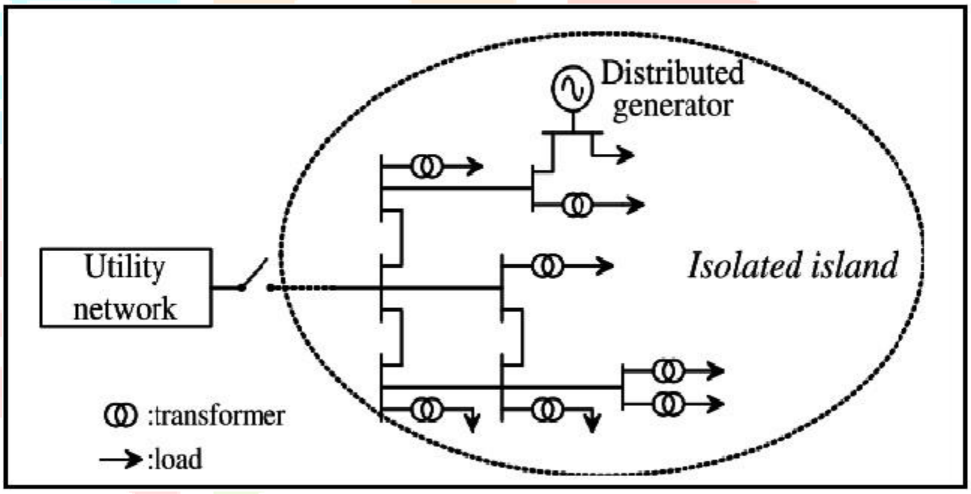

Figure 1:- Islanding Operation

IV. Need for Anti-Islanding

- If an inverter is islanded unintentionally, it might lead to power quality issues like interference with grid protection devices as well as severe hazards to safety of maintenance workers from utility. So it is required to have anti-islanding mechanism in place to avoid the same.
- Safety, reliability and quality of power delivery to the customers are the most important areas of concern for electric utilities. Therefore, to ensure these aspects, it is better to avoid spurious islanding, even if it increases costs and complexity.
- Reactive power unbalance affects the voltage level in the island. An excess of reactive power has the same influence as a shunt capacitor; the voltage increases. A shortage of reactive power naturally causes the voltage level to decrease.
- An effect of large power unbalance in a newly formed island can be serious; such an island may not survive very long. On the other hand, an island with perfect production balance can very well survive for a long time, even if there are no voltage or frequency regulators.
- Reclosing into an island may result in re-tripping the line or damaging the distributed resource equipment, or other connected equipment, because of out of-phase closure.
- Islanding may interfere with the manual or automatic restoration of normal service by the utility [16].

V. Anti-Islanding or Islanding Protection

As already explained that Islanding refers to the condition of a DG generator that continues to feed the circuit with power, even after power from the electric utility grid has been cut off. Hence Islanding can pose a dangerous threat to utility workers, who may not realize that a circuit is still live while attempting to the work on the line. Distributed generators must detect islanding and immediately stop feeding the utility lines with power. This is known as Anti-Islanding. A grid tied solar power system is required by law to have a grid tie inverter with an anti-islanding function, which senses with the power outage occurs and shut itself off. To avoid the Islanding problem, it is recommended that all distributed generators shall be equipped which devices to prevent islanding. The act of preventing islanding from happening is also called anti-islanding. Islanding causes many problems, some of which are listed below:

A. Safety Concern
B. Damage to customer's appliances &equipments
C. Damage of Inverter, electric components & circuits

A. Safety Concern:

Safety is the main concern, as the grid may still be powered in the event of a power outage due to electricity supplied by distributed generators, as already explained. This may confuse the utility workers and expose them to hazards such as shocks.

B. Damage to customer's appliances &equipments:

Due to islanding and distributed generation, there may a bi- directional flow of electricity. This may cause severe damage to electrical equipment, appliances and devices some devices are more sensitive to voltage fluctuations and should always be equipped with surge protectors.

C. Damage of Inverter, electric components &circuits:

In the case of large solar systems, number of inverters is installed with the distributed Generators. Islanding could cause problems in proper functioning of the inverters. 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 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 Islanding causes 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 essential to detect the Islanding quickly and accurately [16].

VI. Islanding Detection Methods

IDM Methods are classified as local and remote methods which are further divided into different levels. Local method relies on monitoring the various parameters at local DG terminal. The local methods are divided into active, passive and hybrid methods. Remote method monitors the parameters between grid and DG terminal. These methods are based on digital signal processing, machine learning, data mining etc.

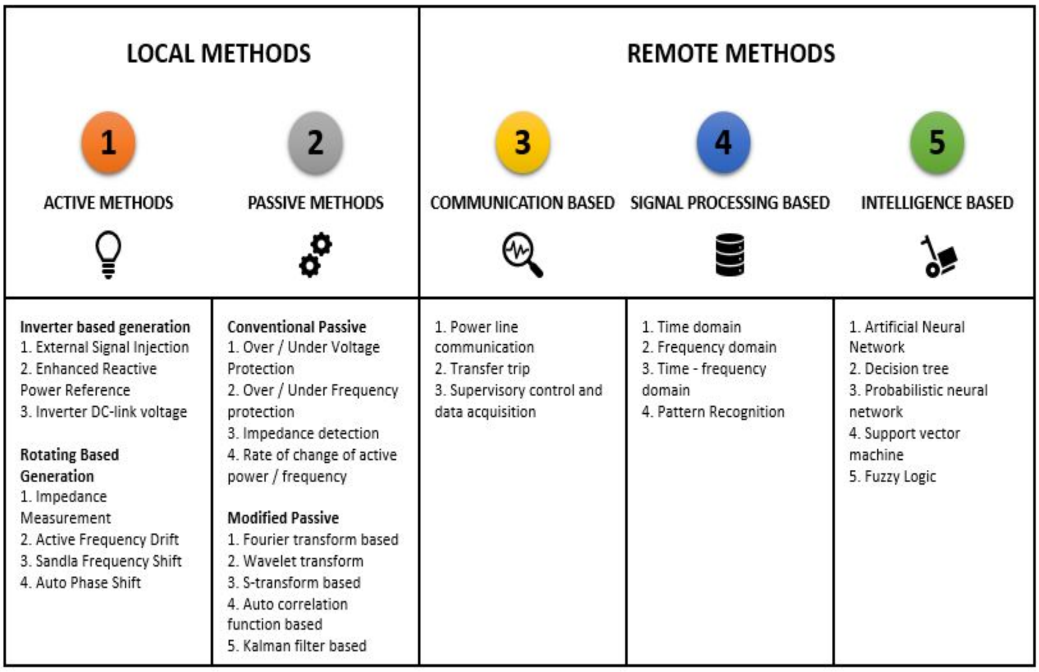

Figure 2:- Classification of various islanding detection methods

A. Active Methods

Active islanding detection methods or techniques works by injecting a signal into distributed generation output. It is necessary to monitor the deviation in the signal so as to detect possible islanding conditions. The system parameters to monitor can be voltage, Frequency and impedance. Disadvantage of active method is system performance degradation because of the injected signal.

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. Some of the active detection techniques are as follows:

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 [11] or at the point where the Reed relay is connected [14]. 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 [19]. The major drawbacks of this method are it is slow and it can not be used in the system where DG has to generate power at unity power factor.

Impedance measurement method: The main philosophy is the same as that of the passive technique that the impedance of the system changes with islanding. In an active direct method, a shunt inductor is briefly connected across the supply voltage time to time and the short circuit current and supply voltage reduction is used to calculate the power system source impedance [11]. However, in an indirect method, a high frequency signal is injected on the DG terminal through a voltage divider. This high frequency signal becomes more significant after the grid is disconnected [13].

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) [20] uses positive feedback which changes phase angle of the current of the inverter with respect to the deviation of frequency at the PCC.

Table 1:- Active methods

Sr. No.	Name of the Method	Short Description
1	Impedance measurement [17]	Impedance is calculated using ROCOV & ROCOC. Finally, Impedance is measured. This method injects high frequency signal. System performance is degraded in this method.
2	Active frequency drift [18]	Distorted inverter current waveform is injected into PCC or DG terminal.
3	Sandia frequency shift[07]	Up gradation in the AFD method where a positive feedback is applied to the inverter voltage frequency.
4	Sliding mode frequency shift[19]	This method uses the phase angle of the inverter output current, which is controlled as a function of terminal voltage frequency.
5	Sandia voltage shift[09]	A positive feedback is applied to the voltage amplitude at the DG or PPC output.

B. Passive Methods

The main objective of passive method is to monitor system parameters at the PCC or DG terminals. The system parameters can be power, impedance, voltage, current, frequency etc. The islanding detection is captured when the main grid gets disconnected from the micro grid or IPDN. The speed of the detection is less as compared to active method. But, this method does not affect any grid operations or power quality .

Rate of change of output power: The rate of change of output power, / dtdP , 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 [6]. It has been found that this method is much more effective when the distribution system with DG has unbalanced load rather than balanced load .

Rate of change of frequency: The rate of change of frequency, / , will be very high when the DG is islanded. dtdf The rate of change of frequency (ROCOF) can be given by [11] f HG P dt df ROCOF 2 , Δ = (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 / . ROCOF dtdf 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.

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 change of frequency over time . Change of impedance: The utility impedance is considerably smaller than the impedance of a power island. The impedance of a section of network will increase when that section becomes disconnected from the utility. Continuous monitoring the source impedance will give the idea of whether the system is islanded or not. Voltage unbalance: Once the islanding occurs, DG has to take charge 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 .

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 . The change in the third harmonic of the DG's voltage also gives a good picture of when the DG is islanded

Table 2:- Passive methods

Sr. No.	Name of the Method	Short Description
1	Over/under voltage protection or Over/under frequency protection [21,10]	Protection relays are used on a distribution feeder to get the abnormal condition. Relay operates when voltage and frequency value exceeds the threshold limit, thus distributed generation disconnects from the main grid.
2	Rate of change of frequency/power[22,23,24]	Initially, threshold limit is set. After particular time interval change in the frequency/power is measured and compared with pre specified threshold limit. Upon exceeding the threshold value, trip setting is set and islanding condition is detected.
3	Phase jump detection[25]	This method is similar to ROCOF/P method. A phase difference between the voltage and current at DG level is monitored.

C. Intelligent IDM's

Intelligent IDM's uses machine learning classifiers and data mining techniques for classification. Intelligent IDM's do not require prespecified threshold values. Initially, the input signal in the form of voltage or current is supplied to the machine learning classifier which then classifies the signal as islanding condition detected or not. Intelligent IDM's are not reliable and accuracy of intelligent IDM's is less than other techniques [26].

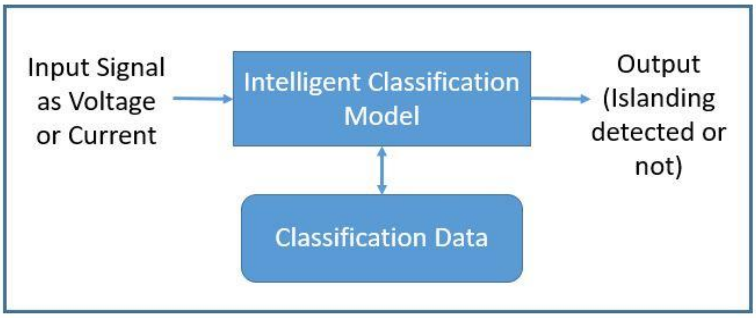

Figure 3:- Operation of Intelligent method

Table 3:- Islanding Detection methods

Classification of IDM's		Detection speed	NDZ	Computation Burden	Merits	Demerits
Local	Active	Medium	Small	Medium	Easy to implement	Performance Degradation
	Passive	Low- For Conventional High- for Modified	Large- For Conventional Small- for Modified	Low	Easy to implement	Difficult to identify threshold value
Remote		High	Very Small	High	Efficient &fast	Complex & Expensive

Table 4:- Comparison of Islanding techniques

Techniques	Advantages	Disadvantages	Example
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	•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
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 grid	•Reactive power export error detection scheme •Impedance measurement scheme • Phase (or frequency) shift schemes (like SMS, AFD, AFDPF and ALPS)

VII. 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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