Islanding Issues of Grid-connected PV Systems

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***Abstract*— 'Islanding' is a term, which refers to the situation when the Distributed generator (DG) continues to power the consumer-end even when the electrical power from the electric utility is no longer present. Islanding phenomenon occurs after the certain part of the utility grid gets disconnected from a large number of inter-connected PVs. It leads to troubles in voltage and frequency control and power quality issues. Therefore there is a need for appropriate anti-islanding measures for grid-connected PV systems. There are two ways to defeat the islanding phenomenon, by reactor insertion method on utility side and capacitor insertion method on PV side. Some of the Islanding detection methods (IDMs) are broadly classifies as Active, Passive and Utility based. Active mode of detection includes impedance measurement, slip mode frequency shift and frequency bias. Passive methods contain over/under voltage and frequency and harmonics detection. Utility-based methods consist of manual disconnection, SCADA, impedance insertion.**

Keyword — current source inverters (CSIs), distributed generator, islanding detection methods (IDMs), point of common coupling (PCC), and phase jump detection (PJD), total harmonic distortion (THD)

I. INTRODUCTION

As the demand for energy is swelling and the resources on earth are declining, there is a need for proper utilization of new and available energy resources. Microgrid serves for this purpose and manages the energy sources like wind turbines, PV arrays, fuel cells to generate electric power. A 'microgrid' is a localized group of electricity generation, its storage and the loads, that normally functions when connected to a traditional integrated grid [1].

For various load conditions, there are chances for DG systems to maintain the stable output power at a stable frequency and voltage. When it is suddenly disconnected from the grid, it may create an islanding condition that may be difficult to sense. As large numbers of DG are continuously adding to the power grid, there is increased risk in the safety of the personnel and harm to the power system. Consequently there is a requirement for detection of islanding and adopting the corrective measures to minimize the risk. IEEE Std 929-2000 and IEEE Std 1547 (in these, the methods used detects the islanding operation within 20ms, which is less than 150ms required in a reclosure as the shortest mechanical reclosing time) are there which require a timely shutdown of the DG system at the point of common coupling (PCC), once it befalls [2].

Islanding has to be removed as soon as possible as it may result in frequency instability and higher proportion of harmonics [3].

If the high speed reclosure is done on the islanding part of the utility grid, then the forced connection results. It not only affects the PVs, but also the grid and the load. The closer the ratio of overall load to the output power, to 1:1, longer the islanding lasts. It implies that by changing this ratio, the islanding process can be suppressed by this phenomenon. Detecting an islanding condition is an important aspect, which includes three largely defined methods.

II. ACTIVE METHODS

These methods for detecting the islanding condition, introduces some changes or disturbances to the circuit and then decides the response to determine if the utility grid is still in connection with the stable voltage, frequency and impedance [4]. If the small perturbation is able to affect the parameters of the load connection within the prescribed necessities, the active circuit causes the inverter to cease power conversion and delivery of power to loads.

A. Impedance Measurement

It measures the net impedance of the circuit being fed by the inverter. It is done by the forcing the current through AC cycle, providing too much current at a time. In normal cases, there won't be any trouble as the grid can bear voltages up to an extent. But in the event of disconnection, even the small forcing results in noticeable change in voltage which helps in islanding detection.

If the utility is disconnected from the grid, the change in current results in a change in voltage and thus power. In this situation, the inverter measures a change in $dV_a/di_{PV\text{-}inv}$ and thus the impedance is measured. The minimum current required for detection of island is the full UVP/OVP window size. For example- with grid connected UVP/OVP at +-20% of the rated voltage, a 40% change is must.

It has small range of non- detection zone (NDZ) for any local load, having impedance greater than grid impedance. It is less effective in multiple inverter case because each inverter introduces its variation, resulting in small change in Va that is undetectable. Voltage flicker, grid instability and false tripping are some other problems for higher impedance grids when this method is used.

B. Impedance Measurement at a specific frequency

In this method the inverter introduces harmonics in the frequency and the impedance is thus measured by the signal from the grid when it fails. After the detection, the harmonics are eliminated. When utility is disconnected current harmonics flows into the load. The linear load produces a change in voltage which can be detected. The amplitude of harmonic voltage generated is proportional to the impedance of the load, from where the method derives the name. Multiple inverters introducing same harmonics may result in false trips. This weakness can be reduced using sub-harmonic injection, which is yet another problem.

C. Slip mode frequency shift (SMS)

It is one of the new and best methods for islanding detection. In it, the phase of the inverter’s output is misaligned with the grid. This system is dependent on actions of a finely tuned phase locked loop (PLL) that becomes unstable when the grid signal is missing. In the case of grid failure, the system will quickly drift away from the design frequency which results in shutdown of inverter. It is implemented with the circuitry already present in inverter. It prevents long run-on steady state operation by using the positive feedback to destabilize the PV inverter when the utility is absent. it requires the inverter to be slightly out of time with the grid and thus has lower power factor. It also has a small NDZ and quickly disconnects.

D. Frequency bias

It forces a slightly off-frequency signal into the grid and also fixes it at the end of each cycle, by jumping back when the voltage passes zero. In it the power factor remains closer to the grid. The main disadvantage is that every inverter has to switch back to zero at the same point otherwise it may result in different directions.

III. PASSIVE METHODS

These methods are mainly applicable to find the transient changes in the grid and to detect voltage changes in the combination of PV inverter and the utility. These methods also searches for grid failure. The passive methods for detection of islanding are given below.

A. Under/Over Voltage Protection (UVP/OVP)

This technique works on the principle of Ohm’s law. At the time of grid failure, current flows from the source maintaining a constant voltage at load. This method has more importance for implementation in grid-interactive inverters. If the change in voltage between PV inverter and utility exceeds a certain limit, then due to this method PV inverter will stop supplying power to the grid. Thus the equipment of consumer will remain safe.

The inverter terminal voltage, Vi at the instant of utility disconnection is given by

$$V_i = \sqrt{\frac{p}{p_{load}}} V_n$$

where, Vn is nominal system voltage

Consider the circuit shown in figure1 [5] in which power flows from node ‘a’ to the RLC load. Node ‘a’ is also known as point of common coupling (PCC) between the utility grid and PV inverter. When utility breaker is closed, real and reactive power flows from PV inverter to node ‘a’ and then power from node ‘a’ flows to the load.

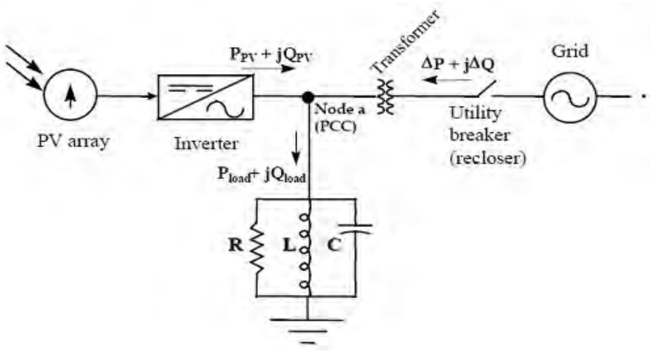

Fig1. PV system/utility feeder configuration showing power flows & terminology

At node 'a' sum of real and reactive power flowing from PV inverter will be equal to the power flowing to the load.

$\Delta P = P_{load} - PPV$

$\Delta Q = Q_{load} - QPV$

Let PV inverter operates with a unity power factor, then

QPV=0,

$\Delta Q = Q_{load}$

The system performance at the time of utility grid uncoupling depends on ΔP and ΔQ, at the time just before the switch opens to form the island. If ΔP is nonzero, voltage of PV array will change and this method can find the variation and avoid islanding. If ΔQ is nonzero, the load voltage will show certain shift in the phase. Now to make ΔQ=0, the frequency of Va is changed by the control system by making changes in inverter output current.

The main feature of UVP/OVP method is that if either of the real power of the load and PV system is not matched, or the frequency of the load does not match with the utility, islanding will not occur. This covers up the huge majority of practical issues.

OVP/UVP is a low cost method for detection of islanding, but they have large NDZ. From this method a system that periodically samples the voltage can be used to detect a fault. These methods are also required for several purposes other than islanding. The systems protected with OVP/UVP are generally used with another protection system because their NDZ is large.

The main disadvantage is their extreme NDZ. Another disadvantage is that, 'reaction time' for this procedure may be variable.

B. Under/Over Frequency Protection (UFP/OFP)

Frequency of the power distributed to the grid is the function of supply voltage. During steady state frequency remains same in entire system. The speed of synchronous generator is proportional to the average frequency. This proportion remains same in case of induction machine also. When the supply of grid is gone, the frequency would drop to the natural resonant frequency of the islanding circuit. For slow changes between production and load, the following equation will give the speed change of machines.

$$\frac{d(\frac{n}{n_s})}{dt} = \frac{P_{(production)} - P_{(load)}}{2.H.S}$$

where, n is the mechanical speed,

ns is the synchronous speed,

H=inertia constant

S=power rating

The relationship between speed and frequency varies during transient conditions such as faults. During faults, the grid frequency measured in buses is not exactly equivalent to speed. A frequency relay takes its decision based on the frequency of the voltage.

The frequency during islanding of system under consideration is given by,

$$w_i = \frac{1}{\sqrt{LC}}\left(1 + \frac{Q}{2qP}\right)$$

Where, P is inverter real power,

Q is inverter reactive power,

q is quality factor,

$1/\sqrt{LC}$ is resonant frequency of inverter

The under frequency situation may occur if the connection to strong grid is interrupted, this condition mostly occurs when local load exceeds the production of DG. Over-frequency can also arise if there is production at the time when islanding begins.

UFP/OFP used rate of change of frequency (ROCOF) algorithm for detection of islanding in power systems. The rate of change of frequency is calculated within a measurement window. ROCOF indicates that a relay uses the time derivative of the frequency to detect islanding. At islanding, the difference between production and load power is compensated 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. This technique is useful to provide signal that is within NDZ for some time. Several others islanding prevention methods act to produce an abnormal frequency or voltage and rely on UFP/OFP to actually deactivate the inverter. One key disadvantage is large NDZ. The grouping of voltage and frequency shifts also results in NDZ which is the major disadvantage.

C. Voltage phase jump detection/ power factor detection/ transient phase detection-

Phase jump detection (PJD) observes the phase difference between the inverter's terminal voltage and output current for an unexpected jump. During normal operation, the inverter current is synchronized with the utility voltage by monitoring the rise and fall of voltage at node 'a' as shown in the figure2. This is usually achieved using an analog or digital PLL. After the grid disconnects, power factor rapidly varies from grid to source. As the circuit is continuously providing current, it would produce a smooth output voltage and results in change of voltage.

For current source inverters (CSIs), when the utility grid is removed, the voltage is not fixed for a long time. But the output current flow is constant i.e, fixed because it follows the output waveform that is given by the PLL of inverter. The main reason behind this is the synchronization between the current and voltage of inverter at zero crossing of voltage. Therefore PV inverter output current turns out to be a constant phase reference. As the frequency has not changed, the phase angle of load also remains constant before removal of utility and therefore voltage must 'jump' to new phase as shown in figure. At the next zero crossing of voltage, the resulting phase errror between new voltage and the inverter's output current can be used to detect islanding. If phase errror is greater than a threshold value, a controller can de-energize or shut down the inverter.

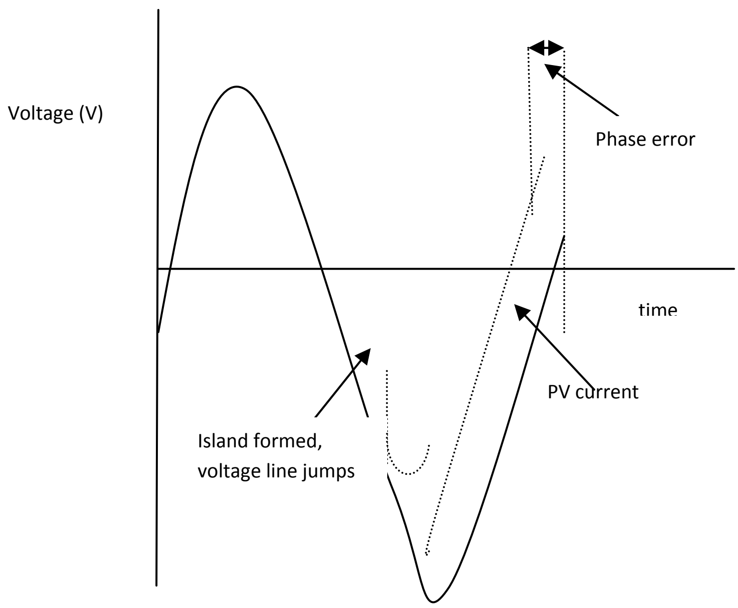

Fig2. Operation of PJD

The main feature of this method is to track the phase of the grid using PLLs. The major advantage of this method is its simple implementation. PJD does not affect the output power quality and has no impact on the transient response of system. The efficiency of PJD is not educed even when multiple inverters are connected to the island.

It is difficult to choose thresholds that provide reliable islanding detection. The thresholds of PJD could be varied for a given installation site, but such specific parameters increase the complexity in installing utility interactive PV systems. Certain loads like motor causes transient phase jumps of considerable size which results in tripping of PV inverter if the thresholds are set too low.

D. Detection of voltage harmonics and detection of harmonics-

The total harmonic distortion (THD) of a grid connected circuit can't be measured directly because of the infinite capacity of grid. In this technique the PV inverter examines the THD of node voltage at node 'a' (shown in figure1) and shuts down if this THD exceeds some threshold. When the grid fails, the THD of local circuit will increase. This results in a very secure method for detecting islanding because of absence of any other sources of THD.

When an island occurs, there are two ways that may cause the harmonics in voltage to increase. First is PV inverter that will create AC harmonics in the AC output current. When utility disconnects, the harmonic current formed by the inverter will flow into the load which has higher impedance than utility. The harmonics produced in voltage are directly proportional to the load. And these changes in harmonics are detected by inverter which can discontinue its operation. Second cause to increase the harmonics is the voltage response of transformer. This technique is not used nowadays as it produces third harmonics because of magnetic hysteresis and non-linearity of the transformer.

It is useful in the detection of islanding under a wide range of conditions. The efficiency in this case doesn't change randomly even in the case of multilevel inverters. It suffers the implementation difficulty equivalent to PJD. It is not always possible to select a trip threshold that provides trustworthy islanding setup. Threshold must be selected higher than THD that can be expected in grid voltage and lower than the THD that will produce during islanding by the two methods given. This method fails if the load has strong low-pass features, i.e. higher Q-value and doesn't have transformer inside the island. It is also unsuccessful when the inverters are of high quality and low distortion outputs.

IV. UTILITY BASED METHODS

It involves the methods which forces the system to go offline at the time of failure. These are discussed below:

***A.** Impedance insertion*

This method involves the insertion of low impedance value on the utility system inside the potential island at point 'b', as shown in figure3.

The switch at node 'b' is generally open. When the switch opens to interrupt in load at 'a', the capacitor bank comes into action, after a short delay [6]. This addition of capacitance results in a step change in phase Φ and decrease in wres, which the under frequency protection device (UFP) can be able to detect. We can also use other impedances such as resistance which produces a change in voltage. But the capacitor banks helps in providing reactive power to the utility. The small delay between the opening of switch and

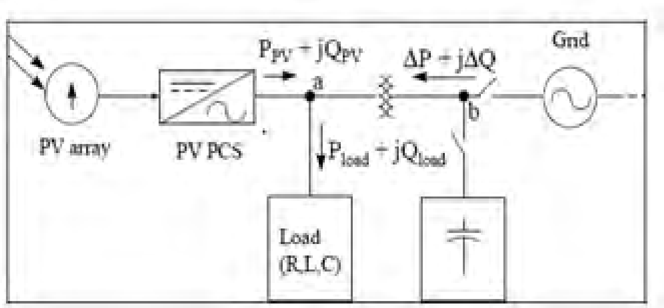

Fig3. Impedance insertion method with a capacitor bank

capacitor insertion helps in preventing islanding, as it does not create a balanced situation between the PV inverter and lagging load. Its drawbacks includes (i) It is expensive (ii) the speed of response is slower than others because of the action of capacitor switches and therefore doesn't meet the standards. (iii) This method requires the installation of equipment on the utility side, which increases the complexity and people don't agree for it easily.

B. Manual disconnection-

Small generator connection requires a mechanical switch that is unplugged by repairman. For large sources, one may simply install dedicated phone hotline to be operated manually to shut down the generators. This method takes time in minutes or hours.

C. Automated disconnection-

In this method signal is automatically sent through grid. For example, power line carrier communication (PLCC) could be installed in all inverters. Such systems will be highly reliable but costly to implement.

D. Transfer-Trip method-

In this method we force a section of the grid into a condition that will surely disconnect the DG systems in the event of a fault. It comprises of automated reclosure systems and external communication systems.

V. METHODS USING COMMUNICATION BETWEEN PV INVERTER AND UTILITY

A. SCADA- supervisory control and data acquisition

When the voltage sensing devices are absent from the local part of utility system, they can be installed in PV inverter. This will detect the changes in voltage and ring the alarm in case of abnormality. Also a reclosure can be coordinated so that out-of-phase reclosure doesn't occur.

If the system has proper communication channels, it will help in eliminating islanding and providing utility to have full or partial control on DG.

Multiple inverters require separate instrumentation or communication links. Utility also need to pay taxes as inverters are installed there.

VI. INVERTER BASED DISTRIBUTION SYSTEMS

For these systems, detection of islanding is done by the help of following approaches which are Decision Tree (DT), Support Vector Machine (SVM), Radial Basis Function Network (RBF), and Probabilistic Neural Network (PNN) [7].

A. DT

It is pattern recognition based popular procedure that is adopted widely in power systems and other areas. The root node is the starting point. Here the outcome is measured by testing it with specified value and the process goes to next level, downwards. This way, a complex decision making process is fragmented down to very simple process that can be followed.

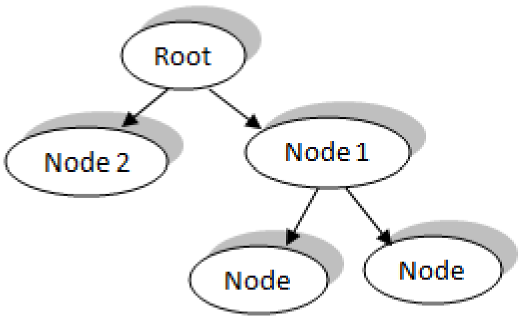

Fig4. Schematic of DT

B. SVM

It is the approach used for classification of islanding and non-islanding cases. It uses various kinds of kernel functions for mapping such as linear, polynomial, and sigmoid and RBF, which helps in providing maximum accuracy levels.

C. PNN

It is used in grouping of power system applications. Faster training makes it more helpful in the discovery of islanding condition. It is based on Bayesian (probabilistic model), which delivers very accurate results.

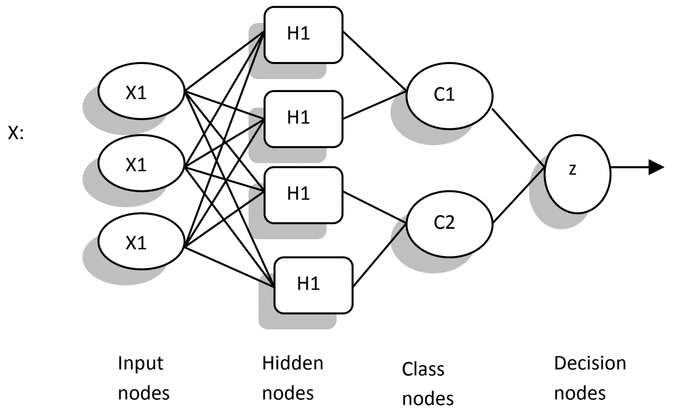

Fig5. Schematic of PNN

In consists of Input, hidden, class and decision nodes. Input nodes are feature vectors, hidden layer or pattern layer forms the product of weight vector and the input for classification. The class node works as summation node for hidden nodes and finally a class is decided on decision node.

D. RBFNN

It is also popular and similar to PNN except for the number of neurons. In PNN, number of neurons is equal to the number of training points, while RBF has less number in comparison to PNN. It also includes three main layers as those in PNN.

E. K-fold cross validation

The amount of data available is limited, thus having one set of training data and one set of testing data can give inaccurate results. Therefore this procedure is used, where the data is divided into k sets. K-1 data is used as training sets for classifier and the remaining set as data to be tested set. This process is repeated k times.

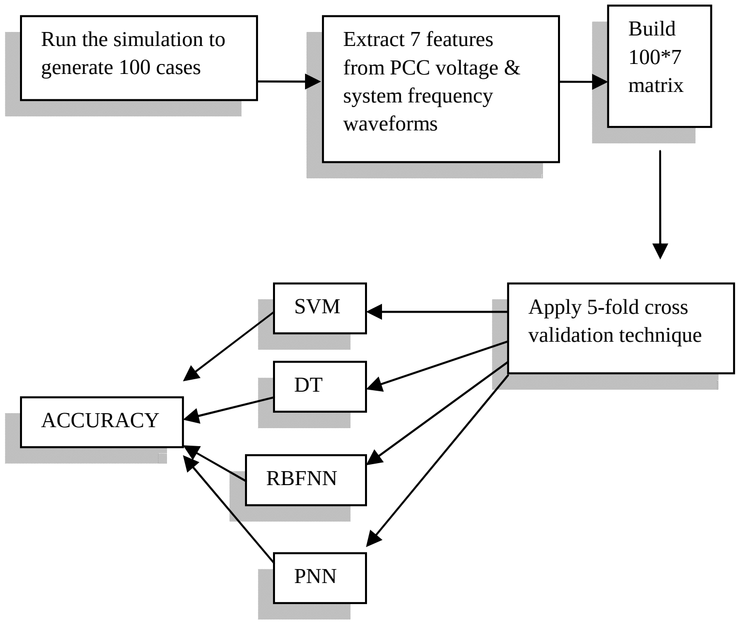

Fig6. Flowchart for K-fold cross validation

A new algorithm which measures the change in δf/δPL is also used for recognition of islanding. Its features are as follows.

It increases the sensitivity and reliability of the protective relays and there is a significant downfall in possibility of false alarms when it is used. The method's paradigm is easy to understand and facilitates in the implementation on field. This method can be included in modern energy management system for development and future planning. Currently it is in use at a steel plant in Southern Taiwan.

VII. CONCLUSION

Islanding cases were generated by having mismatch in active and reactive powers [8]. And non-islanding cases were generated by switching in capacitor banks and loads at different buses as well as faults at different buses. These given approaches help in solidifying the feasibility and right approach catering for various requirements. Thus it can be concluded that islanding can be detected by various methods which are described here. This will help in safety of utility personnel and reduce the complexity in the orderly reconnection of the grid.

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