

A Review on Islanding Detection Techniques for a Grid Connected Photovoltaic Systems

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Abstract: Photovoltaic (PV) system, as a distribution generation (DG) is mostly preferred due to enormous advantages like solar energy available throughout the globe and throughout the year, free of cost, reduced emissions pollution free, highly reliable, no moving parts and less maintenance. Still there are few technical concerns, one of them is islanding phenomenon, hence islanding must be detected and the islanded DG's must be disconnected from the left over part of the system. As per standard codes and grid codes limits, for a low power, less cost, current controlled inverter used in domestic PV system, the inverter should stop functioning after islanding condition is detected. Islanding detection techniques (IDT) are reviewed in this paper for anti-islanding protection of a grid connected PV system. These are broadly classified into four categories namely, Passive methods, Active methods, Hybrid methods and Communication based methods. Active methods are generally preferred over methods due to small Non detection zone (NDZ). Passive methods circuit design and operation are simple but it suffers from large NDZ, hence in performance, as compared to Passive methods. Hybrid method integrates both Passive methods and Active method. The advantages and disadvantages of each method are discussed.

Keywords—Photovoltaic System; Distribution Generation; Islanding Detection; Non Detection Zone; Point of Common Coupling.

1. INTRODUCTION

Photovoltaic (PV) systems consists of a PV array maximum power point tracker, DC/DC boost convert, and a inverter, these systems are interface with power electronic devices [1]. PV systems are one of the promising alternatives as the distribution resources (DR) for distribution generation (DG) using renewable energy sources. As the load increases, the transmission and distribution cost also increases. Due to decreasing cost of DR technologies, connecting DG to the distribution system is an alternative economical solution [2]. The point of contact of DG to electrical power system i.e., electric grid connecting the load, is called point of common coupling (PCC). Grid connected PV system is shown below in figure.1. When a PV system is connected grid, it has to follow technical requirements of interconnections from the utility grid [3-10]. On following the above said rules, leads to extensive safety, good power quality, reliability and interaction of the utility are attained. Any irregular operating conditions would disturb the grid-connected PV systems and needs to be prevented. For a grid connected PV system, accidental islanding is one of the major safety issue.

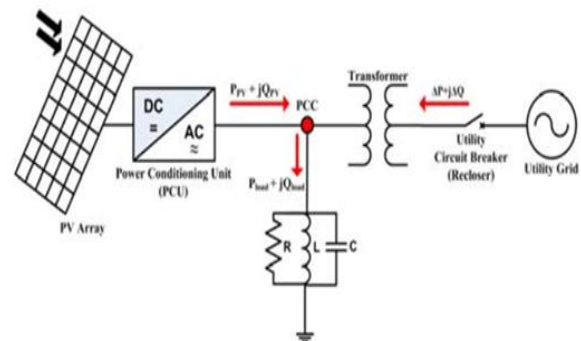


Fig. 1 Grid connected PV system

An island occurs when one or more DG's and some local loads get disconnected from the utility grid and remain energized as a separate body. Utility circuit breaker gets opened during islanding mode and the load continues to receive power from the DG. A grid connected PV system, in islanding mode of operation is shown in figure.2.

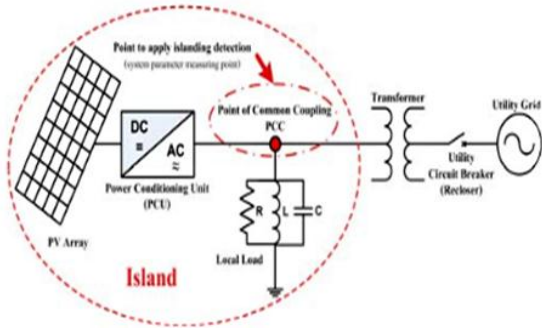


Fig. 2 Islanding mode operation of a grid connected PV system

The problems associated with islanded systems are, there would be variation in voltage and frequency in the islanded part, as the line remain energized during islanding condition, it would be dangerous for the people working on the utility line, when a line of the islanded part is closed out of phase with the grid utility system, the DR in the islanded part gets damaged, islanding would interfere during power restoration of neighboring customers.

Hence, islanding should be detected and the islanded DR's must be isolated from the utility system. Intentional Islanding and unintentional Islanding, are of two types of islanding modes of operation. Intentional Islanding is done for maintenance purpose; it is not dangerous to power system as the problem can be solved when grid is either connected or disconnected. Unintentional Islanding leads to loss of grid synchronization, this causes DG voltage and frequency to go beyond reference values. Hence, Islanding condition must be noticed and islanded system must be isolated from the rest of the system. Islanding detection techniques (IDT) can be classified into local IDT and remote IDT. The first method depends upon the DG parameters, while the second method depends upon the communication between DG and utility grid. The information obtained from the literature review states that none of the methods are perfect. All the methods have some or the other limitations.

Anti IDT for PV systems connected to grid are reviewed in this paper. The working of IDT- Passive, Active, Communication and Hybrid techniques will be discussed in section II. The comparison of different islanding detection techniques are presented in section III. Finally the paper is concluded in section IV.

2. ISLANDING DETECTION TECHNIQUES

Non Detection Zone (NDZ) and quality factor (Q), are the parameters used for explaining Islanding phenomena. IDT under test fail to sense islanding in the range called NDZ. It is the range in which the power mismatch between DG generated and load consumed power is related, the change in active power and the change in active power takes place in this region. The objective of all IDT is to shrink NDZ to zero.

The parameter is Q factor is defined for one cycle and at a particular frequency as the ratio of two $\pi(\pi)$ times maximum energy stored to the maximum energy dissipated in one cycle. Higher the Q factor, slower in detecting the islanding. It depends upon the load inside the island. Q factor is proportional to the NDZ, so a smaller NDZ is chosen. Constant power load that consume constant power and non-linear loads that produce current harmonics do not affect Q factor. As per IEEE 929, a limit of the 5% for the current Total Harmonic Distortion factor with separate limits of 4% for each odd harmonic from 3rd to 9th and 2% for 11th to 15th is recommended. The quality factor ($Q = R * C / L$) as 2.5 for testing condition is allowed by the IEEE Std. 929-2000. The figure.3 shown below summarizes the classification of Local and Remote IDT [11-14].

2.1 PASSIVE METHODS

These techniques rely on information on the deviations like frequency, voltage amplitude, phase at PCC which is in between inverter and the utility at the time the creation of the island [15]. To differentiate islanding operation from some other disturbances, the threshold value should be set carefully in the controlled system. Passive detection techniques do not create any disturbance in the system and are fast in operation but NDZ is large which may lead to failure of islanding detection. The objective of passive methods is to create the Non Detection Zone (NDZ) as small as possible to sense islanding also in the most horrible situation.

2.1.1 Over/Under Voltage (OUV) and Over/Under Frequency (OUF) method

The OUV/OUF (Over-Under Voltage / Over-Under Frequency) method is a passive IDT; its operation depends upon the voltage and the frequency values at the PCC. The above figure.1 shows the direction of flow of power of utility grid, PV system & load. The DG should stop supplying power to the utility grid when PCC voltage amplitude, VPCC or the frequency is outside grid voltage and frequency limits [16-17] shown in table.1.

In a power system under balance condition

$$P_{LOAD} = P_{PV} + \Delta P \quad (1)$$

$$Q_{LOAD} = Q_{PV} + \Delta Q \quad (2)$$

There will not be any active/ reactive power mismatch between grid and PV system when $P_{LOAD} = P_{PV}$ and $Q_{LOAD} = Q_{PV}$. The system behavior, after disconnection of the grid, depends upon ΔP and ΔQ . When the line frequency of the grid and resonant frequency of RLC load are equal, the linear load does not absorb reactive power. When grid is disconnected, $P_{LOAD} = P_{PV}$, the grid voltage V' is given as

$$V' = KV \quad (3)$$

$$K = \sqrt{P_{PV} / P_{LOAD}} \quad (4)$$

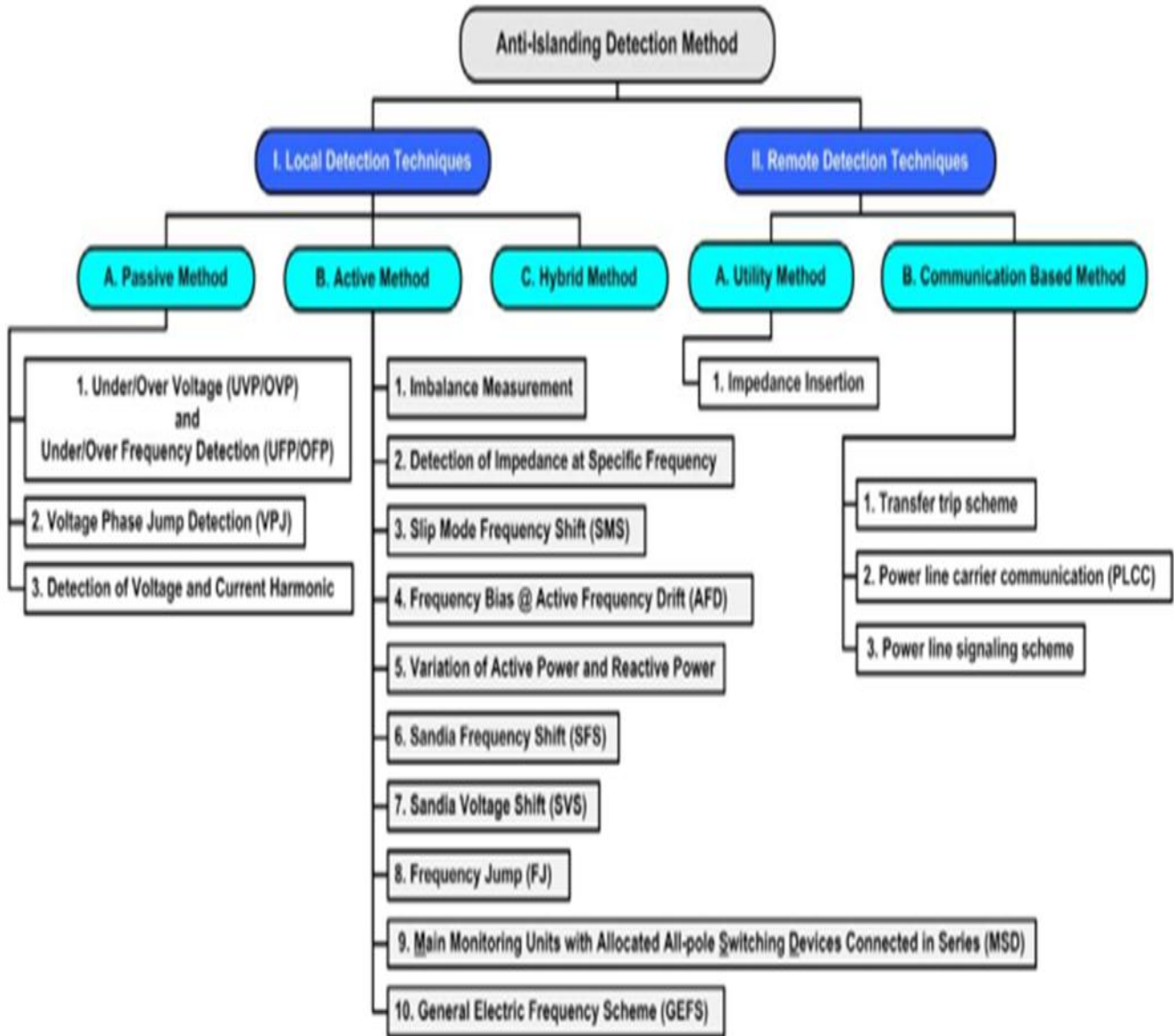


Fig. 3 Classification of Local and Remote islanding techniques

The grid reactive power depends upon the frequency and the voltage

$$Q'_{LOAD} = Q_{PV} = \left(\frac{1}{\omega'_L} - \omega' C \right) \cdot V^2 \quad (5)$$

$$\omega' = \frac{-\frac{Q_{PV}}{CV'^2} + \sqrt{\left(\frac{Q_{PV}}{CV'^2} \right)^2 + \frac{4}{LC}}}{2} \quad (6)$$

A small ΔP results in small ΔV and a small ΔQ results in small Δf , which will be insufficient to disconnect PV and prevent islanding.

NDZ can be calculated from $\Delta P, \Delta Q$ and the settings of threshold values for voltage and frequency. NDZ is shown in the figure.4 below. The main disadvantage of this method is relatively large non detection zone (NDZ) and slow detection

and if the mismatch of power between load and PV is small island detection fails.

Table I. Voltage and Frequency limits

VALUE	MINIMUM	MAXIMUM
Voltage	Vmin = 0.9 pu	Vmax = 1.1 pu
Frequency	Fmin = 49 Hz	Fmax = 51 Hz

Other than protection the OUV/OUF method should serve as an IDT. The OUV/OUF IDT alone is generally considered to be insufficient for islanding protection.

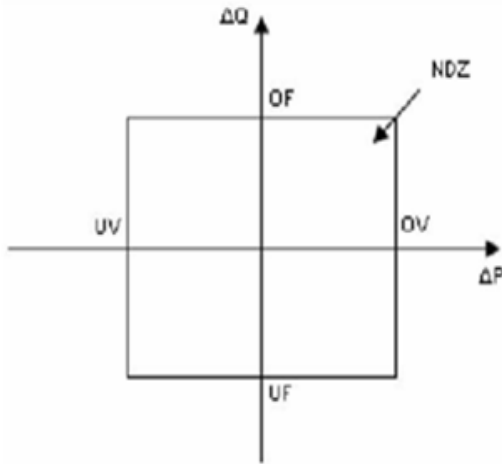


Fig. 4 NDZ of OUV/OUF IDT

2.1.2 Voltage Phase Jump Detection

In this method, the phase difference between voltage at PCC, V_{PCC} and output current of the inverter, I_{PV_INV} are observed. A current source inverter (CSI) uses this technique. If a voltage source inverter (VSI) is used the phase difference between current at PCC, I_{PCC} and output voltage of the inverter is observed, V_{PV_INV} as shown in figure. 5 below. For VSI, CSI the roles of voltage and currents are swapped.

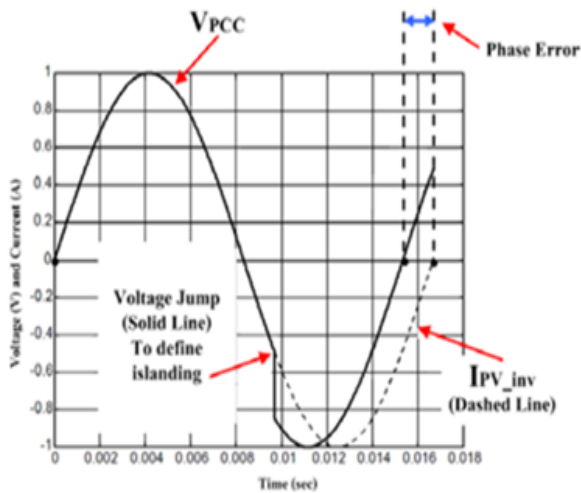


Fig. 5. Operation of PJD method

Using phase locked loop (PLL), the PV systems inverter follows the phase of the grid signal, for CSI the I_{PV_INV} will be synchronized with grid voltage by sensing the rise or fall of V_{PCC} under normal operation. Using digital PLL, this can be done. At the time of islanding mode, phase angle at V_{PCC} will change to match the load phase angle. PJD method will be watching for this sudden change and then islanding will be detected.

2.1.3 Detection of Voltage and Current Harmonics

Voltage unbalance (VU) and Total Harmonic Distortion (THD) of the current are monitored in this islanding method. VU at PV terminals is defined as the ratio of negative sequence of voltage to the positive sequence of voltage at PV output terminals

$$VU = \frac{V_{NS}}{V_{PS}} \quad (7)$$

Where V_{NS} , V_{PS} are negative sequence of voltage and the positive sequence of voltage at PV output terminals respectively. Any change in load of PV system due to loss of utility grid results in variation of harmonics of the current. THD of the current is defined as RMS component of h^{th} harmonic component to RMS component of fundamental harmonic component.

THD is given as

$$THD = \frac{\sqrt{\sum_{h=2}^H I_h^2}}{I_1} \quad (8)$$

Where I_h is the RMS component of h^{th} harmonic component and I_1 is the RMS component of fundamental harmonic component. During islanding condition the loading of PV changes, this leads to voltage fluctuations and in turn gives harmonic currents. At a definite interval of time, VU of three phase of voltage and THD of a phase of current is calculated, if it deviates from the threshold values, islanding will be detected.

2.1.4 Other Passive Methods

Some other passive methods in the literature are comparison of rate of change of frequency (COROCOF) [18], microprocessor based monitoring technique [19], monitoring voltage and changes in the power factor [20] and another method based on directional reactive power measurement [21].

2.2 ACTIVE METHODS

Active IDT is established on the introduction of a small disturbance signal to definite parameters at the point of common coupling [22]. During islanding mode, inverter stops power conversion due to injection of small disturbance signal. Hence, the magnitudes of system parameter will be changing, upon measuring these parameters; islanding mode can be detected [23]. On measuring the corresponding system parameters, islanding condition can be detected, this can be understood using the figure. 6 (a) and (b) shown below.

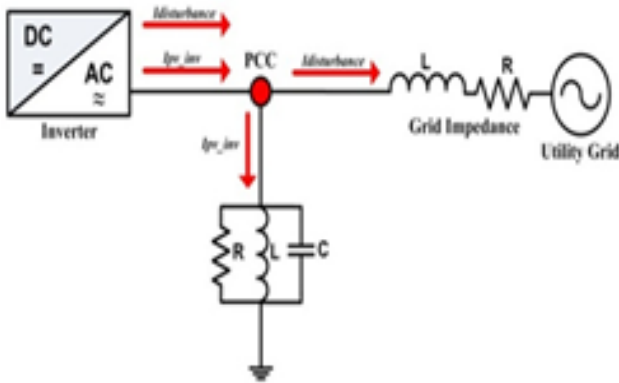


Fig. 6 (a) Path taken by the disturbance signal before opening of circuit breaker

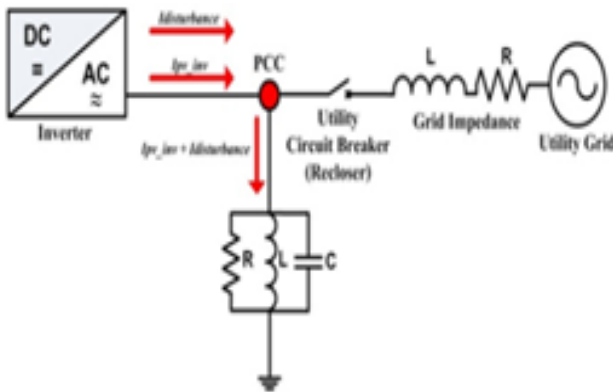


Fig. 6 (b) Path taken by the disturbance signal after opening of the circuit breaker

2.2.1 Impedance Measurement Method

Impedance measurement method detects the change in inverter output circuit impedance that occurs after disconnection of distribution network. The PV inverter appears to the grid as a current source delivering current and is given as:

$$I_{PV_INV} = I_{PV_INV} \sin(\omega_{PV}t + \phi_{PV}) \quad (19)$$

The output power is changed by perturbing the inverter's output current amplitude (I_{PV_INV}) and checks the change in output voltage. Hence, the impedance of the load circuit can be effectively measured [24]. The important property of this method is comparatively small NDZ for case of single inverter with any load. When multiple inverters are connected, this method doesn't perform well. Setting of proper impedance threshold value is a big challenge.

2.2.2 Detection of Impedance at Specific Frequency

This islanding detection method is further extended from harmonic detection method [25]. Harmonic currents of specific frequency are intentionally injected into the PCC. When load impedance is less than utility impedance harmonic current flows into the grid and no irregular voltage appears. But, if the utility is disconnected, harmonic current flows to the load and harmonic voltage is produced and they

can be detected. The amount of harmonic voltage is directly proportional to load impedance at frequency of harmonic currents. In case of multiple inverter, this method gives nuisance tripping problem.

2.2.3 Slip Mode Frequency Shift Method

A positive feedback for island detection condition is used in this method [25]. At the PCC, a positive feedback is applied to phase ϕ_{PV} of the voltage. The grid frequency does not get affected by this method. Power factor angle is function of frequency at PCC, as the phase angle between PCC voltage and inverter output current close to zero. During islanding, frequency of V_{PCC} is perturbed. The inverter phase response curve leads the phase error to increase, and it is a function of positive feedback system and leads to instability. This method gives small NDZ for multiple inverters case. This method is one of a good IDT and its implementation is easy. The disadvantages of this method are transient response problems and poor quality.

2.2.4 Frequency Bias or Active Frequency Drift (AFD) Method

In this method, the waveform of injected inverter current to PCC is marginally distorted as compared to utility voltage. Figure.7 below shows a curve of drift grid voltage Vs inverter current.

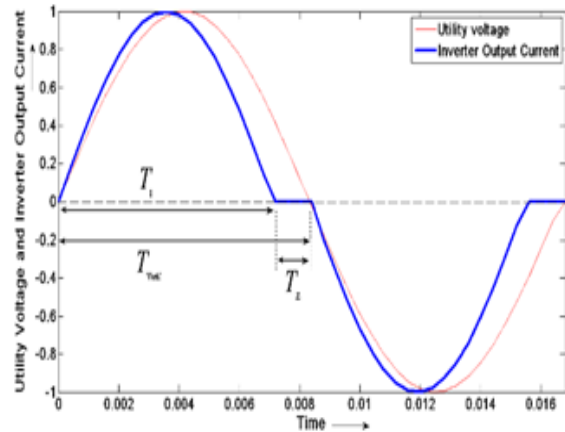


Fig. 7 Utility voltage Vs Inverter Output Current

During islanding condition, the frequency of the grid voltage will move up or down increasing natural frequency Chopping fraction (cf) is defined as ratio of dead time to the period of utility voltage.

$$cf = \frac{2T_z}{T_{v_{util}}} \quad (20)$$

Where T_z is a dead time and $T_{v_{util}}$ is period of utility voltage, As long as utility is connected cf is low, a phase error occurs between utility voltage & inverter output current waveforms. This chopping fraction is low when the utility is connected but in absence of utility, a phase error occurs once utility gets disconnected, which leads to increase in cf. Island will be

detected, if cf is greater than threshold. NDZ is comparatively large for high Q-loads, when compared with other methods

2.2.5 Sandia Frequency Shift (SFS) Method

This method is further developed from Active Frequency drift method, positive feedback is used for island detection. At the PCC, the positive feedback is applied [26]. The relationship with positive feedback is

$$cf = cf_0 + K(f_{PCC} - f_{line}) \quad (21)$$

Where cf_0 is chopping fraction, the controller gain is K, the frequency at PCC is f_{PCC} , line frequency is f_{line} . When utility is connected to load any variation in frequency due to change in load does not effect grid, but if when utility is connected for some reason, frequency increases the frequency error. Due to positive feedback, cf increases till it reaches limit set for OFP and hence islanding is detected.

Among all the active methods, NDZ is smallest, when SFS method is used.

2.2.6 Sandia Voltage Shift (SVS) Method

When the utility is disconnected, for any change in load, voltage amplitude at PCC decreases as a results inverter output current decreases, thereby decrease in voltage, which will be detected by UVP. OVP/UVP trips if the power output of the inverter is either increased or decreased. UVP is preferred generally. A feedback technique [27], inverter responds to small variation in voltage or frequency, leading to change in real or reactive power, which is sufficient to change positive feedback. This method together with SFS is effective in islanding detection. NDZ of this method has very small. There are two disadvantages with method, firstly reduction in power quality, and secondly reduction in PV inverter's operating efficiency.

2.2.7 Automatic Phase Shift (APS) Method

APS method does not have NDZ for some parallel RLC resonant loads. At k^{th} zero-crossing of the terminal voltage, the frequency of voltage is first measured,. The inverter output's current starting angle $\theta_{APS}[K]$ is changed according to the function $f[K-1]$, hence frequency rests at nominal line frequency, is given as

$$\theta_{APS}[K] = \frac{1}{\alpha} * \left(\frac{f[K-1] - 60Hz}{60Hz} \right) * 360^\circ + \theta_o[K] \quad (22)$$

before triggering of UFR/UFR If the steady state of the terminal voltage frequency touches the new phase shift θ_0 is

$$\theta_o K = \theta_o (K - 1) + \Delta\theta * sgh(\Delta f_{SS}) \quad (23)$$

Δf_{SS} is constant and θ_0 is zero

According to this method, when utility gets disconnected, the terminal voltage frequency changes, further leads to triggering of UFR/UFR.

This method functions properly for a system having multiple inverters; for purely resistive loads and parallel RLC loads having resonant frequency equal to the line frequency.

This method gives errors non-linear loads having large inertia, like induction motor.

2.2.8 Robust Islanding Detection Algorithm

The method is developed for DG's using fuel cell which is connected to grid [28]. According to this method grid voltage and frequency are continuously monitored while perturbing perturbs the reactive power. It is observed if reactive power is perturbed by $\pm 5\%$, frequency deviates by $\pm 1\%$. To check for islanding DG real power is reduced to 80% and if the terminal voltage falls below 0.9 p.u then DG is disconnected. The advantage of this method is less NDZ as compared to other methods and the dis-advantage is this method may fail in the case of multiple DG's.

2.2.9 Current Injection Method of Islanding Detection

Electronically connected DG's use this method. On the direct axis or the quadrature axis current controllers of the voltage source converter, a disturbance signal is injected [34] and only direct axis voltage component is compared as the quadrature axis is centered on frequency variation. Islanding condition is given by comparing the reference and control. This method of island detection works well for all loads having $Q < 3.0$, and fails loads having $Q > 3.0$.

2.2.10 Negative-Sequence Current Injection Islanding

This is method for islanding detection is used for DG coupled to a grid with voltage source converter. Negative-sequence voltage at the PCC is checked using a unified three-phase signal processor, when VSC controller injects a negative sequence of current [29]. It decomposes the PCC voltage into direct sequence components, it is an improved PLL. Islanding detection is checked by measuring quantity of negative sequence voltage. This method has no NDZ when compared with other methods, and it is fast acting.

2.3 REMOTE METHODS

These methods work on communication methods. Data is transmitted between the inverter and utility system, PV system utilizes this data to regulate when to stop or continue the operation. For detecting Islanding, trip signal is send to the DG unit when utility circuit breakers are tripped. These techniques are costly and not popular; nevertheless they are reliable and accurate.

2.3.1 Power line carrier communications

A power line carrier method for islanding detection [30-31] can be applied a system configuration as shown in figure.8. A transmitter sends signals on the power line, and this line is tested for continuity to detect islanding. If the receiver does not receive the signal, then it commands the inverter to stop the operation, separate the PV inverter and load from the point of common coupling. This method has advantages like, inverter output power quality is good, this method is applicable for multiple inverter system, NDZ in this method is zero. The dis-advantages of this method are, receiver and

the transmitter cost is high, if the receiver receives duplicate signal from any load, islanding detection would fail.

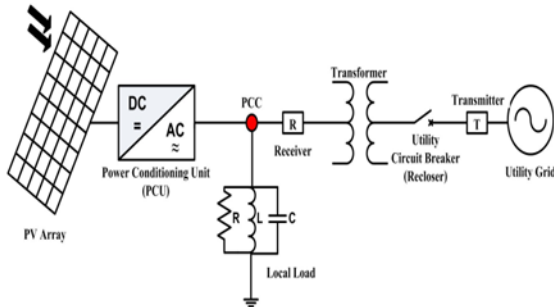


Fig. 8 Circuit of a power system having PLCC control with a transmitter a receiver

2.3.2 Transfer Trip Scheme

The position of all circuit breakers and reclosers are observed in this islanding detection method, depending upon which a DG system would be islanded. Figure.9 shown below explain the operation of transfer trip scheme. A central algorithm calculates the islanded area, when a substation is disconnected. In the unintentional island, inverter is tripped by sending a signal [31]. More coordination amongst DG and utility resources can be obtained. Utility can control DG more effectively by application of this method. The main disadvantages of this method are the cost and complexity. Topology differs when there are many reclosers and the feeder.

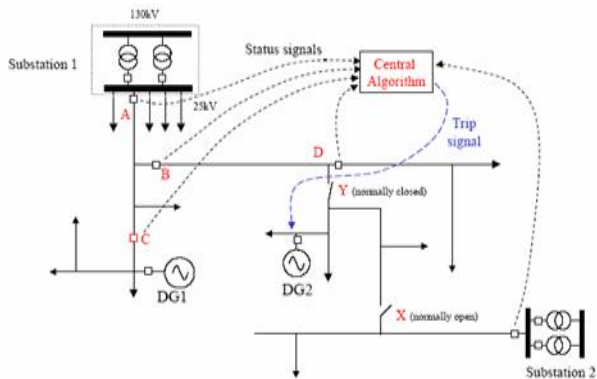


Fig. 9 Transfer Trip Scheme

2.4 METHOD AT THE UTILITY LEVEL

The methods at the utility level [32], generate an abnormal VPCC when the utility is separated; nevertheless, on utility side of the PCC, the islanding detection is done

2.4.1 Impedance Insertion Method

This method connects a capacitor bank to distribution feeder which has a low-value impedance. It is shown below in figure. 10 [33]. Under frequency relay detects, as the

frequency decrease due to imbalance in the reactive power caused by addition of the impedance, when the recloser is opened. The advantages of this method are capacitor banks are easily available; this method can be used in case of multiple inverters and has no NDZ.

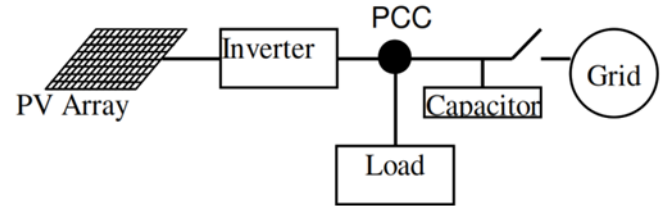


Fig. 10 System in Impedance Insertion Method

2.5 HYBRID DETECTION METHODS

This method detects the islanding condition by using combination of passive methods and active methods. [51] This method uses local measurements of PCC voltage, current signals and injecting high frequency for island detection. Another hybrid method of islanding operation can be identified, when the amplitude or frequency of local load voltage changes, as utility gets disconnected. Other hybrid method of islanding detection uses synchronous reference frame (DQ₀), phase-locked loop (PLL) for island detection [34]. Standard OVP/UVP, OFP/UFP are used in this technique, NDZ is completely eliminated. A hybrid of both passive and active islanding detection methods overcomes the problem of choosing the positive feedback gain in SMS, AFD and SFS algorithms [35]. The advantages of passive and active methods of islanding detection are taken together in other hybrid method of islanding detection pools [36].

3. COMPARISON OF ISLANDING DETECTION METHOD

All the islanding detection techniques discussed above have their own pros and cons, like expensive in implementation, chances of false operation in case of multiple inverters, area of NDZ, power quality, etc., Compares to Passive methods the cost of active methods are reasonable and reliable for islanding detection, hence these reasons active methods are commonly used for islanding detection. Various islanding detection techniques are compared and listed out in Table 1. This is created on monitoring parameter, non-detection zone (NDZ) and speed in implementation.

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Table II Comparison of different islanding techniques

Property	Local Methods			Remote Methods	
	PASSIVE	ACTIVE	HYBRID	UTILITY	COMMUNICATION
Operating Principle	Observes Voltage, Current, Frequency PCC	Disturbance signal injection from DG	Mixture of Passive and Active method	Created equipment installed like impedance	Communication equipment between the grid and DGs
NDZ	Big	Small	Small	None	None
Time of Response	Small	Slightly smaller than Passive method	More than Active method	Fast	Faster
Causes of Failure	If threshold not selected properly	For high Q factor	Lower than Passive or Active method	If impedance less than minimum change of phase.	At ferro resonance
Outcome on Distribution system	No	Voltage variation	Lower than Active method	None	None
Cost of system	Low	Medium	High	Very high	extreme
Efficiency	Depends on supply and load	Island can be detected at balance condition	Very effective	Very effective	Most effective

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