Islanding Detection Techniques for Grid Integrated Distributed Generation –A Review

Ch. Rami Reddy*‡, K. Harinadha Reddy**

*Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Guntur, India.

*Department of Electrical and Electronics Engineering, Nalanda Institute of Engineering and Technology, Guntur, India.

**Department of Electrical and Electronics Engineering, Lakireddy Bali Reddy College of Engineering (A), Krishna, India.

(crreddy229@gmail.com, kadapa.hari@gmail.com)

‡ Corresponding Author: Ch. Rami Reddy, Research Scholar-Koneru Lakshmaiah Education Foundation and Asst. Prof. Nalanda Institute of Engineering and Technology, Guntur, India. Tel: +91 9154463336, crreddy229@gmail.com

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Abstract- This paper focuses on the review of various islanding detection methods for integrated Distributed Generation (DG) system. Due to the advantages of renewable power generation, the grid integration of DG sources is increasing day to day life. One of the major problems with these integrated DG systems is an unintentional islanding. The islanding is caused in the power system, if DG supplies power to local load connected after disconnecting from the main grid. As per various DG interconnection standards, the islanding should be detected within 2 seconds after islanding. The islanding detection methods are classified as remote techniques which work on utility side and local techniques which work on DG side. This paper discusses the survey of various islanding detection methods with their performance indices. The advantages, disadvantages, power quality issues, Non Detection Zone (NDZ), balanced islanding detection possibility and standards of each method are presented in detail. This paper is very useful to the researchers for selecting the better method for future islanding detection.

Keywords: Islanding detection; Distributed Generation; Smart grid; Local islanding; Remote islanding, Non detection zone.

Nomenclature:

DG	Distributed Generation
NDZ	Non Detection Zone
CB	Circuit Breaker
PID	Passive Islanding Detection
AID	Active Islanding Detection
HID	Hybrid Islanding Detection
PCC	Point of Common Coupling
THD	Total Harmonic Distortion
OUV	Over Under Voltage
OUF	Over Under Frequency
ROCOF	Rate of Change of Frequency
ROCOP	Rate of Change of Power
V-THD	Voltage THD
I- THD	Current THD
ROCOFOP	Rate of Change of Frequency over Power
PJD	Phase Jump Detection
VU	Voltage Unbalance
ROCOFORP	Rate of Change of Frequency over Reactive Power
ROCOPAD	Rate of Change of Phase Angle Difference
ROCONSVAC	Rate of Change of Negative Sequence Voltage and Current
ROCOPSVAC	Rate of Change of Positive Sequence Voltage and Current
PNSVNSC	Phase angle between Negative Sequence Voltage and Current
ROCOEVORP	Rate of Change of Exciter Voltage over Reactive Power
CBSS	Circuit Breaker Switching Strategy
DWT	Discrete Wavelet Transforms
WPT	Wavelet Packet Transforms
ST	S- Transforms
FGNA	Fast Gauss Newton Algorithm
SFS	Sandia Frequency Shift
AFD	Active Frequency Drift
APS	Automatic Phase Shift
AFDPF	Active Frequency Drift with Positive Feedback
SVS	Sandia Voltage Shift
SMFS	Slip Mode Frequency Shift

NSC	Negative sequence Current
NSV	Negative Sequence Voltage
PSC	Positive Sequence Current
PSV	Positive Sequence Voltage
RPI	Reactive Power Injection
IM	Impedance Measurement
ROCOV	Rate of Change of Power
PLCC	Power Line Carrier Communication
SCADA	Supervisory Control and data Acquisition
TTS	Transfer Trip Scheme
ANN	Artificial Neural Network
DT	Decision Tree
SVM	Support Vector Machines
PNN	Probabilistic Neural Networks
CF	Correlation Factor
MG	Micro Grid

1. Introduction

To meet the energy consumption demand of the world, all are looking towards the renewable DG [1]. 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 [2]. 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. The major problems with such DG systems are unintentional islanding [3]. The principle of islanding detection is presented in Fig.1. The DG is integrated into the grid with transformers and CB. If the main CB is opened, the islanding is occurring with local load and DG. The islanding detection methods are classified as (Fig.2) local islanding detection and remote islanding detection methods. Further the local islanding techniques are classified as passive, active and hybrid methods [9], [55]. The two main parameters influence the understanding of islanding are NDZ and DG interconnection standards. The region of values where an islanding technique fails to detect islanding is called NDZ [10-11]. The DG interconnection standards will gives the issues of DG with the existing power network. The optimazation algorithms, energy management systems and controlling of islanding grids is impportant to protect the system [153-157].

This paper reviews various islanding detection methods in detail with their advantages and disadvantages. This paper is very helpful to the researchers while selecting an efficient islanding detection technique for future islanding detection.

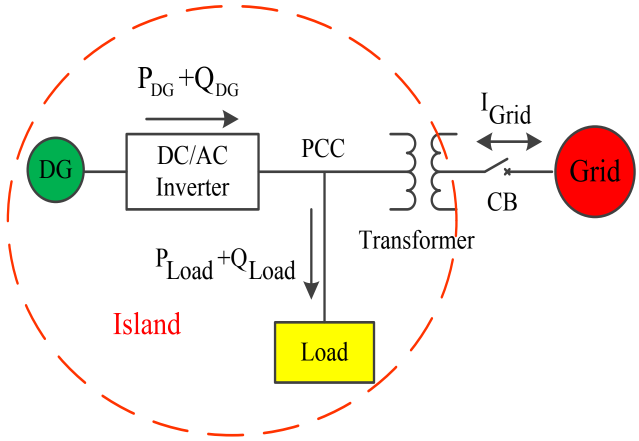

Fig.1. Islanding in the power system

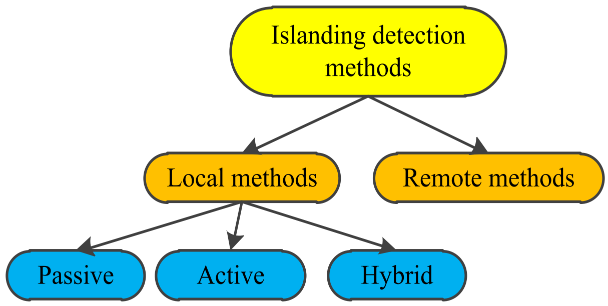

Fig.2. Classification of islanding detection methods

Table - I. Island detection time, frequency and voltage ranges of various standards [4-8]

Standard	Quality factor	Detection time (ms)	Range of frequency	Voltage range
IEEE 1547	1	t < 2000	59.3 ≤ f ≤ 60.5 Hz	88% ≤ V ≤ 110%
IEC 62116	1	t < 2000	f0 - 1.5 ≤ f ≤ f0 +1.5	85% ≤ V ≤ 115%
Korean Standard	1	t < 500	59.3 Hz ≤ f ≤ 60.5	88% ≤ V ≤ 110%
UL 1741	≤1.8	t < 2000	Setting value	Setting value
VDE 0126-1-1	2	t < 200	47.5 Hz ≤ f ≤ 50.2 Hz	80% ≤ V ≤ 115%
IEEE 929-2000	2.5	t < 2000	59.3 ≤ f ≤ 60.5Hz	88% ≤ V ≤ 110%
AS47773-2005	1	t < 2000	Setting value	Setting value

2. Local Islanding Detection Methods

2.1 Passive islanding detection (PID) techniques

The PID methods will use, the local parameters such as voltage, current, frequency, active power, reactive power, phase angle, THD etc. at PCC to detect the islanding. When the DG is in the grid connected mode, there cannot be more deviations in these passive parameters, but when the system is islanded, the variations in these parameters are outside the standards and are used to detect islanding [12]. The detection process of PID techniques is depicted in Fig.3. Care must be taken while setting the threshold values in order to separate islanding with non islanding events such as switching transients, short circuit faults. These methods are very simple to implement, no power quality issues and accurate methods, but are suffering with large NDZ [13-14].

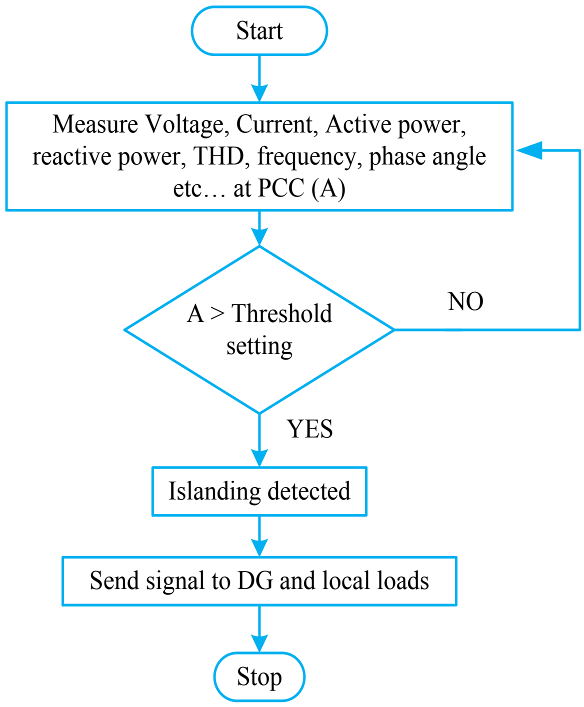

Fig.3. General flow chart of PID techniques

2.1.1 Over/under voltage, over/under frequency method

The first PID technique is an OUV / OUF method. In this method the voltage and frequency of the system at PCC are observed to decide whether islanding is taken or not. The voltage and frequency threshold values can be calculated from equations (1) and (2)

$$\left(\frac{V}{V_{max}}\right)^2 - 1 \le \frac{\Delta P}{P_{DG}} \le \left(\frac{V}{V_{min}}\right)^2 - 1 \quad (1)$$

$$Q_f\left(1-\left(\frac{f}{f_{min}}\right)^2\right) \le \frac{\Delta Q}{P_{DG}} \le Q_f\left(1-\left(\frac{f}{f_{max}}\right)^2\right) \quad (2)$$

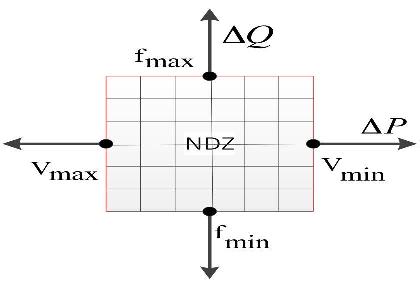

Fig.4. NDZ of OUV/OUF, PID technique

Where V_{max}, V_{min}, f_{max} and f_{min} are the maximum voltage, minimum voltage, maximum frequency and minimum frequency thresholds respectively. As per Table-I, the values of $V_{max,}$ $V_{min,}$ f_{max} and f_{min} are 110%, 88%, 60.5 and 59.5 Hz respectively [15-17]. It can detect islanding, when the voltage and frequency exceeds or lower the thresholds [52]. The NDZ of this method is more and is shown in Fig. 4. from which this method fails to detect islanding inside the box.

2.1.2 Rate of change of frequency

The performance of the ROCOF passive method is based on the measurement of frequency at PCC. The frequency measurement is done through phase locked loop (PLL). In the cases when the grid system is lost, a change in DG's loading is happening and its instantaneous output frequency is changing called as ROCOF [18], [22], [47-48]. The expression for the ROCOF is given by equation (3) [19], [150].

$$\frac{df}{dt}(k) = \frac{f(t_k) - f(t_k - \Delta t)}{\Delta t} \quad (3)$$

Where f (t_K) is the frequency at the time of k^{th} sample, f (t_k-Δt) is the measured value of frequency Δt before the k^{th} segment time i.e. t_k-Δt. The NDZ of this method is less compared to OUV/OUF passive method [4-5] and also this method fails to detect balanced islanding. The setting of threshold values is very important for separating islanding and switching events in this technique [8].

2.1.3 Rate of change of active and reactive power (ROCOP)

In this method the ROCOP is used to detect islanding. During normal grid connected operation, the changes in ROCOP are less, and at islanding they are more [20]. Care should be taken while selecting the threshold values, for differentiating switching events with islanding events [21]. This method is very efficient for unbalanced load and failed to detect islanding when it is under balanced islanding [40].

2.1.4 Voltage unbalance (VU)

This method detects islanding based on VU of three phase voltages at PCC. When the loss of main source occurs, even a very small change in load leads to VU. The ratio of NSV to PSV is used to detect islanding as voltage unbalance factor (VUF) [22-23]. Equation (4) defines the VUF as

$$VU_t = {NSV}/{PSV} * 100 \quad (4)$$

Where VU_t is the VU at t^{th} instant of time. The equation (5) will indicate, the deviation of VU from study state value of voltage during load switching and islanding

$$VU_t = \frac{VU_s - VU_t}{VU_s} \quad (5)$$

Where VU_S is the voltage unbalance of predefined value and VU_t is the voltage unbalance at t^{th} instant of time.

2.1.5 Phase jump detection

This method detects islanding, when the phase angle between voltage and current of inverter output is more than a predefined threshold value [25]. The modified PLL is used to detect the deviation in phase angle. When islanding occurs, the inverter output current remains same, but the inverter voltage swings its path which is shown in Fig. 5. Due to new path of inverter voltage, the phase error occurs. If this error is more than a threshold value, then islanding is confirmed and inverter is tripped. The advantage of this method is, it has no effect on transient response and power quality [24].

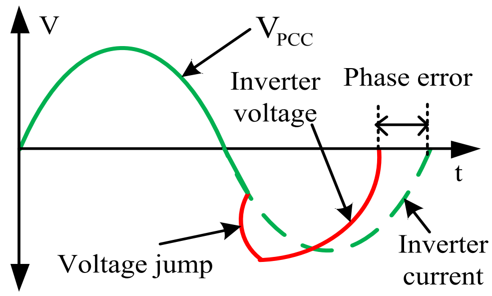

Fig. 5. Principle of PJD operation

2.1.6. Voltage unbalance and THD based islanding detection

It detects the islanding condition, when the combined changes of both VU and current THD is more than a predefined threshold value. Generally in the grid connected system, low harmonics (<5%) are present [25], [50]. When the system is islanded, the load is connected to the inverter. Due to change in the impedance of load, harmonic content of voltage and currents are increased. Harmonics also increases when non linear loads are switched. Hence, to overcome the false tripping for islanding events, VU method [23] is used in combination with the THD technique. Rate of change of reactive power (ROCORP) in combination with THD is also used to detect islaning [26], [53-54] when both ROCORP and THD are more than preset values.

2.1.7. Change of source impedance

In general the DG has small impedance, if it connects to grid its impedance is more than the impedance of the source. When the system is islanded under unbalanced load after disconnecting form micro grid (MG) its impedance at PCC is changed [27]. By continuously monitoring the impedance at PCC, the islanding is detected. But this method fails to detect islanding for balanced loads.

2.1.8. Rate of change of voltage and power factor

This method is useful particularly when the DG and the load are same capacity and also for the detection of loss of parallel feeders. The islanding is achieved by continuously monitoring the combination of ROCOV and power factor at PCC [28]. The change in voltage magnitude and power factor are made, when the system is islanding. This method clearly separates the islanding and switching events.

2.1.9 Rate of change of frequency over active power

This technique uses the ROCOF over active power (df/dp) for islanding detection. This method has a less NDZ compared to ROCOF relay [29-30], [51]. It will also find the islanding for small and medium power islanding conditions. The setting of threshold values is difficult for this technique because ROCOF and ROCOAP settings are required.

2.1.10. Rate of change of frequency over reactive power

This is one of the best methods for islanding detection of DG system [30]. Compared to ROCOF, ROCOP, ROCOV, OUV/OUF passive methods this method separates islanding and non islanding events perfectly [31]. It will detect islanding when the ROCOFORP is more than a predefined threshold value. It will also work for zero power islanding detection with smaller or zero NDZ. It is one of the best technique among available PID techniques.

2.1.11. Rate of change of phase angle difference

In this method the phase angle between voltage and current at PCC are computed for islanding detection [29], [33]. The voltage and current signals at PCC are used for computing the phase angle difference. The islanding is detected if the ROCOPAD is beyond a specified threshold value. This method has NDZ less compared to ROCOF technique [31]. It can also work for balanced islanding detection.

2.1.12. Rate of change of negative sequence voltage and current

The sequence analyzer will separate the positive, negative and zero sequence component of voltages and currents from unbalanced voltages and currents obtained at PCC. The zero sequence components present only when the system is associated with ground. The negative sequence components present during the islanding operation. The positive sequence components will present in all modes. By observing the ROCONSV and current the islanding is detected [34-36], [49]. In the grid connected mode these deviations are not present, but in islanding condition these changes are more and an islanding is detected. Balanced islanding is possible with this method.

2.1.13. Rate of change of positive sequence voltage and current

The positive sequence components of voltages will present in all modes of micro grid like grid connected, autonomous and islanding modes. By using the sequence analyzer, the positive sequence component of voltage and current are computed [37], [56]. The islanding is detected, if the values of ROCOPSVAC are more than the threshold value. The balanced islanding is detected, with zero NDZ with this method [38]. It will exterminate the switching events and islanding events perfectly.

2.1.14. Phase angle between NSV and current

In this method, at PCC the voltage and current are calculated. By using least square method the phasor of voltage and current magnitudes are calculated [39]. The sequence analyzer will calculate the NSV and NSC. The phase angle difference between NSV and NSC can found by the equation (6)

$$\phi = \angle \mathrm{NSV and} \angle \mathrm{NSC} \quad (6)$$

If the phase angle ϕ is more than the specified threshold value, then islanding is detected. This value is positive for islanding events where as it is zero for non islanding events such as fault switching, load switching [121].

2.1.15. Rate of change of exciter voltage, over reactive power

In this technique excitation voltage and reactive power are selected for islanding detection because the excitation voltage and reactive power are directly varied with variation of excitation but not on inertia constant. The active power and frequency are depends on the inertia constant of generator, but not on the excitation [40]. So the time taken for small changes in frequency and active power is more due to inertia. However the affectibility of reactive power and excitation are very fast for a variety of excitation. First, the reactive power and the exciter voltage are measured from which, the ROCOEVORP (dE/dQ) is calculated [120]. If the ROCOEVORP is more than the preset value, then islanding is confirmed. Otherwise, non islanding is confirmed. The excitation and CB switching strategy (CBSS) is also used for islanding detection [41-42]. This method can detect balanced islanding with small NDZ but will take more time for detection than ROCOF, OUV/OUF relays.

2.1.16. Transient component based approach

In this method, transient component of signals and positive sequence superimposed component current angle at PCC are used for islanding detection. The transient index value is computed from the voltage signals obtained at PCC. The variations in both the parameters are used to detect islanding. This method accurately separates, the switching events from islanding events. It will detect accurately the balanced islanding [44].

2.1.17. Forced Helmholtz oscillator

This is a new passive islanding detection method introduced for detecting islanding phenomena, for both inverter based DG s and synchronous DG systems. It will use the modified frequency at PCC for islanding detection. This method is based on the chaos concept and it is implemented with forced helmholtz oscillator [45-46]. It is better suited for inverter based DG than synchronous DG. The islanding is detected with this method upto ± 0.4% of power mismatch. It will clearly validate the non islanding events.

2.1.18. Switching frequency of the inverter

This method will detect the islanding, by observing the switching frequency of the inverter [57]. During grid connected mode the frequency is constant, but at islanding it is changed. The authors proposed that, this method can detect islanding within 20 ms after islanding, which is less than the shortest CB reclosing time of 150 ms [58]. It is best suited for inverter based multiple DG units. The NDZ of this method is zero.

2.2. Signal processing methods

2.2.1. S-Transform (ST)

The improvement of WT with phasor data is known as ST [64]. The ST advancement is utilized for islanding detection and analysis of power quality related issues based on running at changeable and expandable narrow gaussian windows. In the presence of noise, multi resolution technique based ST is used to get accurate results after processing each phase frequency. In [67], the spectral energy content of the S contour was computed after the NSV and current signal were processed using ST. Similarly, in [68-69] NSV was processed using ST. Islanding is detected by computing energy content and the standard deviation of the contour. The weakness of using this ST technique is, it will degrade the power quality due to transients [70-74].

2.2.2. Wavelet transforms (WT)

Wavelet transforms are the best engineering tools for speech and signal processing applications. By observing the voltage waveforms at PCC the islanding is detected with wavelet transforms. Hence it is a passive method. This method has given a good result for the inverter based DG systems with quality factor of 2.5 for parallel RLC loads. The quality factor of loads is nearly 2.5 or less [60] and this application has no effect on power quality. By getting information from the ROCOP at PCC the wavelet packet transform detects the islanding case neatly from switching events by using node rate of change of the power index [61]. Spectural change in higher components of voltage change at PCC is used to detect islanding with nearly zero NDZ at the worst case of islanding within 2.5 cycles [62-63], [74].

2.2.3. Fuzzy and S- Transform

In this method discrete fast S- transform and fuzzy rule based approach was used for islanding detection. The NSV and NSC of target DG are inputs to the S-transform [59]. The fuzzy rule based approach separates the islanding and non islanding events. It is already tested for multiple DG units and obtained the islanding detection within one cycle

[7]. This method clearly classifies the switching events from islanding events, even at heavy disturbances.

2.2.4. Discrete wavelet transform (DWT) and S transform

Wrenching out of NSV from DG sources is used to detect islanding, with DWT and S-transform approach. After processing the NSV with S-transforms and wavelets in different cases the islanding is detected. It not only finds the islanding events, can also find the type of DG system [64]. After processing the voltage signal at PCC, the power quality issues and islanding events are classified [65]. Only with DWT, the islanding is detected by using current signals at PCC within one third cycle (5.5 ms) for 60hz system at closely balanced islanding [66].

2.2.5. Fast gauss newton algorithm (FGNA)

A new factor based fuzzy inference system is modelled by extracting the features from FGNW, in order to differentiate the islanding and non islanding events. A forgetting factor weighted error cost function is minimized by the well known Gauss-Newton algorithm and the resulting hessian matrix is approximated by ignoring the off-diagonal terms to yield the new FGNW algorithm to estimate, in a recursive and decoupled manner, all the above voltages and current signal parameters accurately for realistic power systems even in the presence of significant noise [71]. This technique detects islanding in one cycle.

2.3 Artificial intelligent techniques (AIT)

After extracting the features from the signal processing methods, the AIT, such as artificial ANN, DT, SVM, PNN detects the islanding. The computational burden is more with these techniques, but the advantage of this method is, that they reduce the NDZ to zero [72-73]. The islanding detection with SVM is proposed in [75], concludes the voltage and current are the best indices for islanding detection than active and reactive powers and frequency. In [76] DWT and SVM are used to detect islanding events and different types of short circuit faults. Auto regression signal modelling is used to extract data from voltage and current signals at PCC, later with the use of SVM the islanding is predicted in [77]. The random forest technique is used to separate islanding and non islanding events, and also to protect DG from nuisance tripping with reduced NDZ [78]. In [79], [80] PNN and PNN in combination with wavelet is proposed. In [81], Bayesian classifier is utilized which achieves higher accuracy, but the computational burden was high. Decision tree based classifier is implemented in [82], [83] and in [84] various intelligent techniques are compared and a decision tree based classifier is found to have best accuracy. Then in [85], the fuzzy rule based system combined with decision tree is proposed. The technique is easy to implement and is insensitive to noise.

2.3. Active islanding detection techniques

The active islanding detection (AID) methods, detect the islanding by introducing a small perturbance into the system at inverter side [86-87]. This perturbance has an effect on power quality during grid connected and islanding modes of operation. The NDZ of these methods is low compared to PID methods. Some of the researchers advised to introduce a 1% of perturbance to DG capacity, which cannot degrade the power quality [88-89], [16]. The AID techniques will work at balanced islanding with less NDZ. The existing AID techniques are explained as below

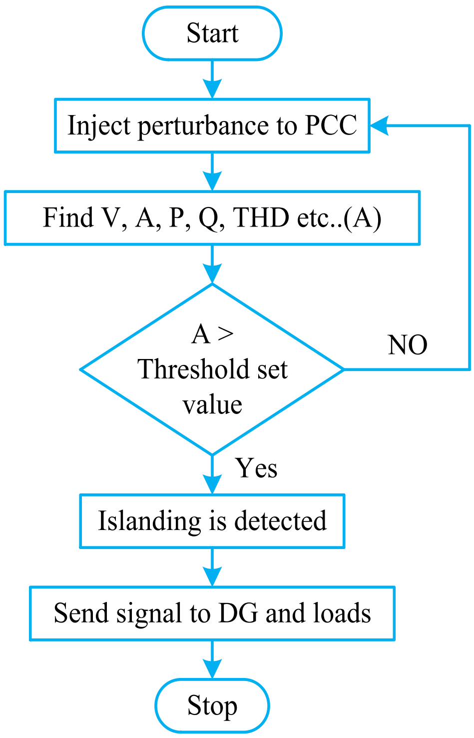

Fig.6. General flow chart of AID techniques

2.4.1. Sandia frequency shift (SFS)

This method is developed by sandia national laboratories, USA, hence it is called a sandia frequency shift method. In this method we will inject a small current into the output current of inverter as shown in Fig.7. The blank interval T_Z injected into the system will increase the output current frequency compared to the previous cycle [90]. The frequency increases because of positive feedback voltage, and will be continued till it reaches the over frequency protection (60.5 Hz). In the grid connected mode this injected wave cannot effect any parameter, but when it is islanded the frequency of output current increases. The increase in frequency error is given by equation (7)

$$cf = cf_0 + K(f_{PCC} + f_{Grid}) \qquad (7)$$

The increase in frequency will depend on the parameter K, and will responds for the speed of the detection technique [91]. The improved SFS method will increase the power quality compared to SFS, by injecting only positive feedback reactive current [92-93], so that it will affect only reactive current and less active current. The SFS with negligible NDZ is presented in [94-96], by designing suitable parameters with the use of the phase angle frequency curve.

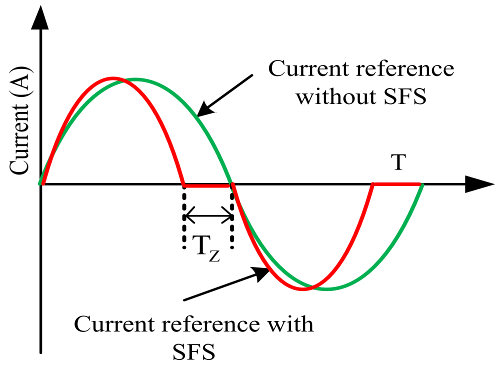

Fig. 7. Current disturbance injected by SFS method

2.4.2. Active frequency drift (AFD)

In the AFD method, by introducing a short period of zero time as shown in Fig.10, the inverter output current is increased or decreased. The ratio of dead time T_z to a half period of voltage waveform is called chopping fraction cf (8).

$$cf=T_Z/T_{Grid} \tag{8}$$

The chopping fraction drifts the frequency increase or decrease. When it reaches OUF threshold, the islanding is detected. This method has large NDZ [97]. It was failing to detect balanced islanding and has a limitation on injecting THD [98]. The advantage of this method is, this method can be implemented easily with micro controllers. To remove the problems of NDZ and balanced islanding, APS technique is introduced.

2.4.3. Automatic phase shift (APS)

According to the inverter output voltage, in APS method the starting phase angle of the inverter output current is changed. When the frequency of the voltage stabilizes, an additional phase shift is introduced each time. This method guarantees that the frequency of inverter voltage reaches OUF relay thresholds when islanding occurred, and islanding is detected. The disadvantage of this technique is, the frequency is deviated and line current is not in phase with voltage for resistive loads also [99]. This method performance is again improved by a new method called active frequency drift with positive feedback (AFDPF) [100].

2.4.4. Active frequency drift with positive feedback (AFDPF)

In AFDPF method, a feedback is given from output, to drift the frequency more or less than threshold values. The OUF relay detects islanding. The weakness of this method is it will degrade the power quality, due to the disturbance injection [100]. The balanced islanding is detected within 6 cycles [102]. The AFDPF method with double feedback will detect islanding earlier than AFDPF method [101] and it can also be applied to multiple inverter based systems.

2.4.5. Sandia voltage shift (SVS)

By applying feedback to the amplitude of voltage, SVS method detects the islanding. This is one of the best methods among feedback based methods, but has an effect on power quality and transient response of the grid connected system. A current feedback signal is applied to the voltage source converter, which amplifies the voltage at PCC. If the voltage at PCC reaches OUV standards, the islanding is detected [4].

2.4.6. Slip mode frequency shift (SMFS)

SMFS method uses positive feedback for modifying the voltage phase angle and frequency at PCC [104]. The deviation of frequency from the nominal frequency at PCC is given by (9). Grid frequency and inverter phase response curve is shown in Fig.10.

$$\theta_{SMFS}=\theta_m \sin\left(\frac{\pi f\text{-}f_g}{2f_m}\right) \tag{9}$$

Where f, f_g are inverter and grid frequencies, θ_m and f_m are the islanding detection parameters. Injected feedback leads to deviation in phase angle, which leads to deviation in frequency shown in Fig.8. If the frequency in steady state reaches OUF threshold values, the islanding is confirmed and inverter is tripped. This method has large NDZ and power quality problems [103]. In advanced SFS, the balanced islanding is detected and NDZ is reduced to zero by changing the islanding detection parameters, as per the local impedance value [105].

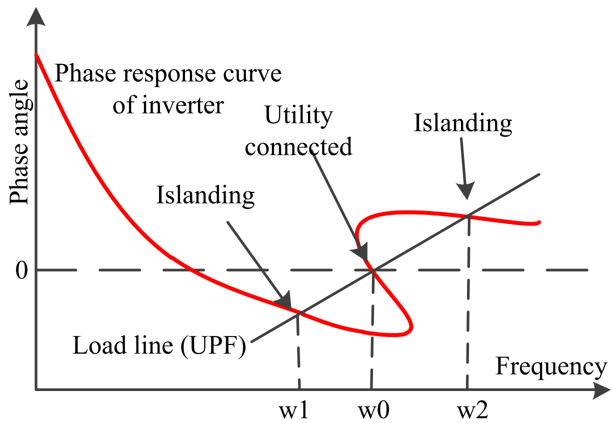

Fig.8. Principle of SFS technique

2.4.7. Negative sequence current (NSC) injection

In this method, the islanding is detected by measuring the negative sequence impedance (NSI) by injecting small NSC (< 3%) through the grid interfacing voltage source converter. The NSC is injected to PCC through dq/abc controller. The ratio of NSV to NSC is NSI [110-111]. If it is more than a predefined threshold value, an islanding is detected. With this method the islanding is detected within 60ms even in the worst case of islanding [108-109]. In [106-107] by injecting NSC, islanding is detected and fault ride through of active and reactive power also achieved.

2.4.8. Reactive power injection (RPI)

By injecting reactive power with rotating reference frame controller and by observing the ROCOF in combination with reactive power (Q/f droop) the balanced islanding is detected. The RPI technique has minor impact on the grid connected systems [112], because when the grid frequency is normal we cannot inject the reactive power. In reference [113] a bilateral reactive power (Capacitive + Inductive) is injected periodically with half of the grid frequency to deviate the frequency at islanding, by observing ROCOF at PCC the islanding is detected at balanced islanding.

2.4.9. D axis and Q axis current injection

In this method a small harmonic current is injected through VSC with d-axis and q-axis controllers of dq/abc controller. The d- axis perturbance leads to deviations in voltage at PCC, where as the q- axis perturbance leads to changes in frequency [114]. By observing the changes in voltage amplitude, and ROCOF at PCC the islanding is confirmed. The d-axis current injection based hybrid analyzing technique detects islanding within 130ms for perfectly balanced system [115]. To improve the performance as rapid response, in the d-axis current injection based method, the PID controller is replaced with wavelet fuzzy neural network intelligent technique [116]. The q- axis current perturbation based relay [117] changes the reactive power at PCC and detects balanced islanding within 200ms and unbalanced islanding within 100ms and also clearly differentiates between islanding and non islanding events.

2.4.10. Impedance measurement (IM)

In this method the islanding is detected by measuring the impedance at PCC. The ratio of ROCOV and ROCOC gives impedance. During grid connected mode its value is less and after islanding it is heavily changed [29]. It has a weakness with multiple inverters, when all the inverters are not operating at the same point. The active feedback islanding detection scheme is presented in [118], reduces the NDZ of passive impedance based scheme. Impedance based AFD islanding technique is presented to overcome the above drawbacks [119].

2.5. Hybrid islanding detection (HID) methods

The HID methods combine both the features of PID and AID techniques. Only PID methods are suffering with large NDZ, and only AID methods are facing power quality problems due to perturbance. Hence, to overcome these problems, HID techniques are developed. When the PID techniques suspect the islanding, the AID techniques confirm the islanding and non islanding events [122-126], [152]. The flow chart of HID technique is presented in Fig.9.

2.5.1. Voltage unbalance (VU) and frequency set point

The islanding detection method presented in reference [23], combines two passive parameters such as THD and VU. This method is more efficient than single parameter passive techniques. But wrongly detect islanding case when large loads are switched. To overcome this problem VU and ROCOF based HID is proposed in [127]. This method detects islanding when VU (4) and ROCOF are more than a threshold value. This method discriminates the islanding and non islanding events perfectly.

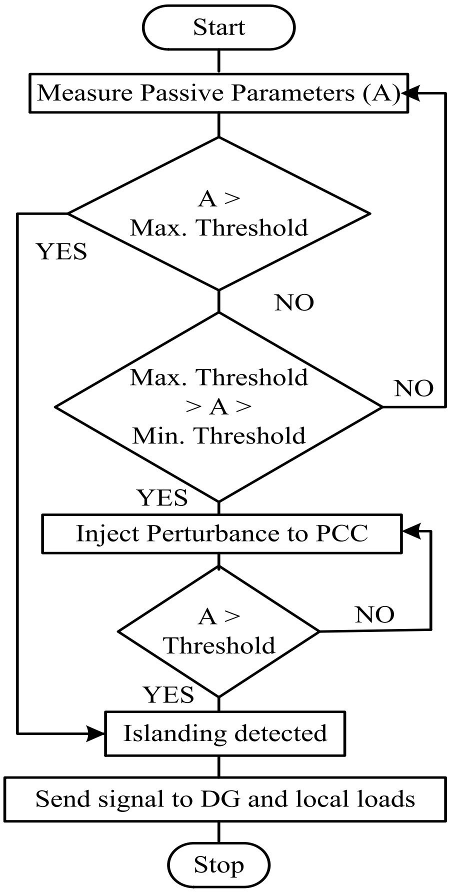

Fig.9. Flow chart of HID techniques

2.5.2. Voltage and real power shift

In this method the ROCOV is calculated for five cycles as per equation (10). If the ROCOV is more than a minimum voltage set point, then islanding is doughtable. If it is more than a maximum voltage set value, which indicate the huge power difference between load and generation and an islanding is confirmed [128].

$$ROCOV=\left|\frac{1}{5}\sum_{i=1}^{5}\left(\frac{dV}{dt}\right)_i\right| \tag{10}$$

But if the ROCOV is in between maximum and minimum voltage set points, then it will suspect an islanding or a non islanding event. In this case to confirm the islanding and to separate between non islanding events the real power of any one DG is increased or decreased. Now again the ROCOV for another 20 cycles (11) is calculated and is compared is calculated for another 20 cycles, and is compared with ROCOV after for each five cycles. If it is same or more, then islanding is confirmed, otherwise non islanding [129].

$$\text{ROCOV}=\left|\frac{1}{20}\sum_{i=1}^{20}\left(\frac{dV}{dt}\right)_i\right| \quad (11)$$

2.5.3. Voltage fluctuation injection

The islanding is detected in this method by periodically switching higher impedance load at grid side. The ROCOF, ROCOV and the correlation factor (CF) are used to confirm the islanding. When there is a large power mismatch, the islanding is confirmed with ROCOF and ROCOV with large threshold values. For small power mismatch, if ROCOF and ROCOV are more than small threshold values, immediately AID technique comes into action [4]. The CF value is checked and if it is also more than the threshold value, then islanding is confirmed, else it is considered as a non islanding event. With this technique, the authors confirmed the islanding within 0.216 seconds for four types of loads.

2.5.4. SFS and Q-f islanding technique

This HID technique uses the SFS-AID technique and ROCOF-PID technique [131]. For huge power variation, only ROCOF confirms the islanding, if ROCOF is more than a high set value. For small power balanced islanding, the ROCOF set value is decreased and is low set value. If ROCOF is in between low and high set values, the AID SFS method comes to action. The islanding is confirmed if ROCOV also more than the set value. The advantage of this method is, it can accurately detect islanding and confirm the non islanding events [4].

2.5.5. ROCOF and reactive power injection

The ROCOF relay failed to detect islanding, when the active power imbalance is below 15% [132], [151]. To improve the performance of ROCOF relay for worst case of islanding, reactive power injection based ROCOF, HID technique is proposed [133]. In this method the reactive power is injected continuously through q controller and reactive power versus frequency curve (Q/f) is plotted for islanding detection. In [122] Q/f droop curve and ROCOF are used for islanding detection. Due to continuous injection of reactive, this method is best suited for multiple mixed types of DG systems [134]. The NDZ is reduced than ROCOF-PID technique.

3. Remote islanding detection (RID) methods

RID methods are usually operating at the utility level. These techniques are high reliable than local islanding techniques, but they are highly expensive [8], [135-136]. Some of the remote islanding techniques are as follows. These methods will depend on some other parameters and devices, as like local techniques they cannot work independently. But these techniques, reduces the NDZ of local methods.

3.1. Transfer trip scheme (TTS)

This method detects islanding by using communication signals between utility grid and DG [137-138]. The sending of signal is initiated by a device capable of islanding detection. The signal transmitters are located at different locations on the feeder depending on the geographical area (Fig.10). After receiving the signal from the transmitters, the communication (fiber optics, digital communication, analog communication, etc..) channel transmits the signal and the receiver trips the DG and CB. The advantage of this technique is, it reduces the NDZ of local techniques. But the demerit is the high cost of implementation [139-140].

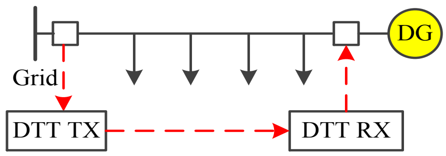

Fig.10. TTS-islanding detection principle

3.2. Power line carrier communication (PLCC)

In PLCC islanding technique, the transmitters are placed on grid side and receivers are placed at the DG side [8]. The receiver, receives the signals from the transmitter and sends signals to the inverter. During islanding, no signals are received from the transmitter, hence islanding signal sends to the inverter [141-144]. The best method for islanding detection is to use, non local islanding detection techniques [145].

3.3. Signal produced by disconnect

This technique is same as that of PLCC, with a different transmission system such as telephone link, microwave channel and etc... it is directly communicating with DG system. The advantage of this system is full control of grid and DG is possible. Its drawback is, it is expensive and difficult in designing [146].

3.4. Supervisory control and data acquisition (SCADA)

By observing the auxiliary contacts of all CB on the utility side, the islanding is detected with SCADA. When an islanding is occurring, a series of alarms are activated to trip the DG [7]. This method is highly efficient in islanding detection, but its development is difficult and requires too more sensors which are expensive. When the system is busy, it will take more time to respond [147-149].

Table-II: Comparison of PID techniques

Name of the PID technique	Detection time	NDZ	Power quality

OUV/OUF [15]	4 ms to 2 sec	Large	*
ROCOF [18]	24 ms	+	*
ROCOP [20-21]	> one cycle	+	*
V-THD and I-THD [25]	45 ms	More with high value of Q	*
ROCOFOP [51]	100 ms	Lower than ROCOF	*
PJD [25]	10-20 ms	+	*
VU [22]	53 ms	Large	*
VU and THD [23]	> ROCOF (within 2 s)	Medium	*
Switching frequency [57], [152]	< 40 ms	1.60%	*
Voltage and frequency [152]	150 ms	∆	*
ROCOFORP [30]	Not mentioned, better than 16 passive parameters	#	*
ROCOPAD [33]	< ROCOF	+	*
ROCONSVAC [34-36]	80 ms	#	*
ROCOPSVAC [37]	10 ms	#	*
PNSVNSC [39]	Within quarter cycle (4.16 ms)	#	*
ROCOEVORP [40]	Not mentioned	#	*
ROCOEVO with CBSS [41]	300 ms for balanced islanding & 100 ms for unbalanced islanding	#	*
Transient component based [44]	< One cycle (20 ms)	∆	*
Forced Helmholtz oscillator [45]	Maximum 440 ms	∆	*
Signal processing methods			
Wavelet [152-153]	50 ms	Nearly zero	*
DWT [76]	Within one cycle (5.5 ms)	#	*
WPT [152]	Very small	#	*
Wavelet coefficients [153]	24 ms	#	*
DWT & ST [66]	Within one third of cycle	#	*
Fuzzy and ST [153]	Within one cycle (20 ms)	#	*
FGNA [71]	Within one cycle (20 ms)	#	*

Table-III: Comparison of AID, HID and RID techniques

Name of the AID technique	Detection time	NDZ	Power quality
SFS [94-96]	0.5 ms	∆	Degrade
AFD [97]	Within 2 seconds	∆	Degrade
APS [99]	+	+	Degrade
AFDPF [100]	< AFD	∆	Slightly degrade
SVS [29]	Not reported	+	Slightly degrade
SMFS [104]	0.4 sec	< AFD	Transient stability impacted
NSC Injection [110-111]	60 ms	#	Not reported
RPI [112]	100 ms	#	Slightly degrade
D and Q axis injection [114]	100 to 200ms	#	Slightly degrade
IM [29]	700 to 900 ms	+	Harmonics injected
Phase locked loop [152]	Within 1 second	+	Less
Goertzel algorithm [153]	400 ms	#	Slightly degrade
Virtual resistor [152]	39 ms	#	Slightly degrade
Virtual capacitor [153]	51 ms	#	Slightly degrade
Name of the HID technique	**Detection time**	**NDZ**	**Power quality**
ROCOV and power [128]	Within 2 seconds	+	Slightly degrade
VU and SFS [127]	Not reported	+	Slightly degrade
ROCOF and IM [153]	210 ms	+	Not reported
ROCOV and Frequency [48]	33.3 ms	∆	Degrade
VU and THD [28]	Within 2 seconds	+	Degrade
Name of the RID technique	**Detection time**	**NDZ**	**Power quality**

PLCC [8], [141-142]	200 ms	#	*
SCADA [7]	Speed is low, when system is busy	#	*
Signal produced by disconnect [146]	300 ms	#	*
TTS [137-138]	Not reported	#	*

Note: # = Zero; * = No impact; + = Small; ∆= Very small

5. Research Gaps and Possible Research Areas

It is found from the literature the majority of the PID methods are failed to detect the balanced islanding. The balanced islanding is one which has same load and DG capacity after islanding. The AID and HID methods sometimes treating non islanding events as islanding and vice versa. The PID methods has more NDZ. Hence the researchers should target to reduce the NDZ of PID methods, to reduce the power quality degrade effect in AID and HID methods. To work on the balanced islanding detection by PID methods.

6. Conclusion

In this paper a brief survey of islanding detection techniques for grid integrated renewable energy resources is presented. As per IEEE 1547 standards the islanding should be detected withib 2 seconds after islanding. These islanding detection techniques are classified as local and RID techniques. The local islanding methods are again classified as PID, AID and HID techniques. It is found that the NDZ of PID techniques is more than AID and HID techniques. In AID techniques, the NDZ is less but they degrade the power quality. The HID techniques combine both the features of AID and PID techniques and their NDZ is reduced than PID techniques. The RID techniques are free from NDZ but they are very complex to implement than local techniques. Most of the PID methods are failed to detect balanced islanding and some of the methods cannot work for multiple DG connected systems. Future work comprises of balanced islanding detection with passive methods, to develop the methods to work on multiple DG systems without degrading power quality and nuicesance trippings.

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