A Comprehensive Review of Active Islanding Detection Methods and Islanding Assessment in a Grid Connected Solar Based Microgrid

Kumari Namrata, Akshit Samadhiya, and Papia Ray

Abstract In this literature, different islanding and their detection techniques are overviewed for the power system network consisting of distribution system along with Distributed Generator (DG). As penetration of renewable energy utilization and DG are increasing continuously, it is important for a power system engineer to detect and mitigate any possible occurrence of islanding event. Islanding Detection Methods (IDMs) are divided as remote and local methods. Remote methods requires communication system for efficient operation while local methods are again categorised into three types active, passive and hybrid methods. Active methods are based on direct interaction with the power system operation via perturbation and passive methods are based on utilization of local parameters while hybrid methods are the amalgamation of active and passive. These IDMs for DG are described and analysed as per detection time, advantage, disadvantage, Non Detection Zone (NDZ) and power quality issues. This work will give a broad idea for selecting the better one of IDMs. Selection of IDMs are based on four relevant performance indices. A better IDM has a minimum NDZ with lower detection time without degrading the power quality. Integration of Renewable energy sources can pose technical challenges. Unintentional Islanding may result in issues such as system instability, degradation in power quality and malfunctioning of protection system. Fast and efficient methods needs to be developed to prevent unintentional islanding. To achieve better reliability and high accuracy, different islanding detection methods (IDMs) have been discussed in this research work. An extensive analysis of IDMs based on different technical aspects is presented. A techno-economical comparison of IDMs is presented based on recent trends related to monitoring islanding events. Additionally, a simulation study for a grid connected Solar based Microgrid is presented to analyze five different islanding

K. Namrata (✉) · A. Samadhiya
Department of Electrical Engineering, National Institute of Technology Jamshedpur, Jamshedpur, India
e-mail: namrata.ee@nitjsr.ac.in

P. Ray
Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India
e-mail: papiaray_ee@vssut.ac.in

S. R. Salkuti and P. Ray (eds.), *Next Generation Smart Grids: Modeling, Control and Optimization*, Lecture Notes in Electrical Engineering 824,
https://doi.org/10.1007/978-981-16-7794-6_7

detection methods under unintentional islanding. Comparison of IDMs is based on trip signal generation under two different loading scenarios during an islanding event.

Keywords Islanding · Distributed generator · Local parameters · Non detection zone · Power quality · Photovoltaic · Utility grid

Nomenclature

IDMs	Islanding Detection Methods
MG	Micro-grid
DG	Distributed Generator
NDZ	Non Detection Zone
PQ	Power quality
P	Active Power
Q	Reactive Power
CB	Circuit Breaker
AI	Anti-Islanding
ID	Islanding Detection
PCC	Point of common coupling
ΔP	Active Power mismatch
ΔQ	Reactive Power mismatch
Δt	Detection time
Ed	Error detection ratio
RID	Remote islanding detection
LID	Local islanding detection
PID	Passive islanding detection
AID	Active islanding detection
HID	Hybrid islanding detection
TT	Transfer trip
SCADA	Supervisory control and data acquisition
OUV	Over/Under voltage
OUF	Over/Under frequency
PJD	Phase jump detection
PLL	Phase Locked Loop
VU	Voltage unbalance
PSV	Positive Sequence Voltage
THD	Total harmonic distortion
CBSS	Circuit breaker switching strategy
AFD	Active frequency drift
Cf	Chopping fraction
Tz	Zero or dead time
SFS	Sandia frequency shift
SVS	Sandia voltage shift

APS Automatic phase drift
IM Impedance measurement
NCCI Negative component of current injection

1 Introduction

Global consumption pattern has seen continual annual growth over the last two decades and is expected that the demand may even double in coming 10 years [1]. A shift towards renewable based low carbon technologies in power generation has been observed. Key factors such as technological advancement in semiconductors, Solar cells and wind turbines, decarbonisation of power sector, efficient power electronics converters and advanced control strategies allows accelerated deployment of renewable energy sources. Renewable based Microgrids ensures less transmission losses and can even improve the power quality and voltage profile of the Grid [2]. However, increasing penetration of renewable based energy system can pose certain challenges to the power quality, stability and safety of the Grid [3].

Renewable based generation systems or Distributed generations (DGs) as shown in Fig. 1 can either operate in grid connected mode or isolate itself to provide power to local loads. However, events related to unintentional islanding of DGs may occur which needs prompt attention. These events leads to instability, transient

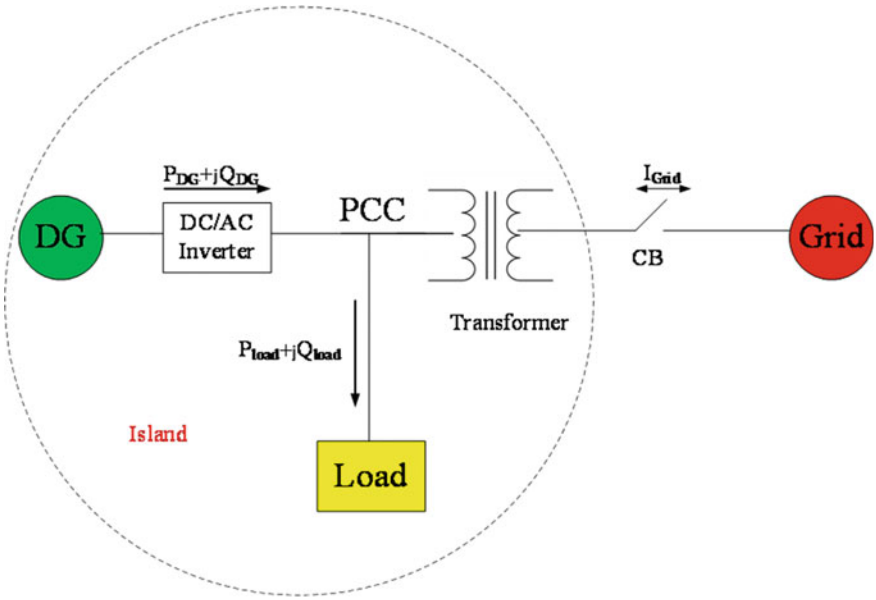

Fig. 1 Power islanding condition

Table 1 Technical requirements and guidelines defined by various for monitoring islanding events in grid connected DGs [4, 5]

Standards	Quality factor	$t_{detection}$ (ms)	Allowable frequency range (Hz)	Allowable voltage range (%)
IEEE:1547	1	<2000	49.3–50.5	88–110
IEC:62116	1	<2000	$f_0 - 1.5 \leq f \leq f_0 + 1.5$	88–110
IEEE:929-2000	2.5	<2000	49.3–50.5	88–110

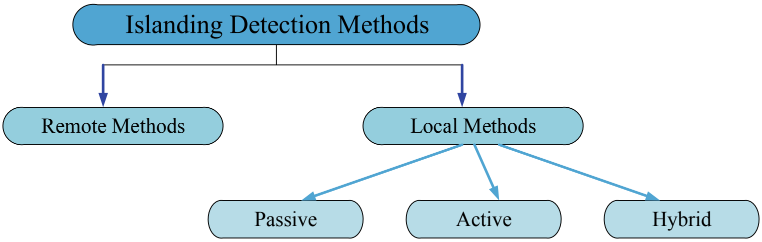

Fig. 2 Taxonomy of islanding detection methods

overvoltage, frequency deviation, malfunction of protection system that degrades the power quality of the system. Certain standards are adopted widely to address unintentional islanding issues for grid connection of DG units. Some standards are listed in Table 1 that provides technical requirement for Anti islanding capability of DG units before integration in the power system network.

For detection of the islanding phenomena different methods are shown in Fig. 2 remote islanding and local islanding methods. Again local islanding methods are categorised as passive, active and hybrid methods [6]. A detailed assessment and comparison of various Islanding Detection (ID) methods along with benefits and limitations are presented for monitoring islanding based activities.

- Considering the future outlook of the electric power industry, wide scale penetration of renewable technologies such as solar, wind, fuel cell etc. in the form of distributed generation requires efficient converters, adoption of advance control strategies and latest technological advancements.
- Detection of islanding condition is also an important issue to deal with.
- Due to challenges related to the power quality of the system, progress in the field of islanding detection have gained momentum in recent years.
- However, very few publications have discussed about the fundamental problem, comparison between contemporary and advance detection techniques, classification of IDMs, performance indices for assessing IDMs, advantages and disadvantages of each IDMs in terms of Non detection zones (NDZ), detection time and power quality. Hence, a comprehensive analysis on various aspects of islanding detection is worth to review and compile.

The work is segregated into following sections. Section 2 deals with challenges related to unintentional islanding and its effect on the power system. Section 3 discusses about various performance indices for selecting a better IDM. Section 4 broadly discusses about different types of local, remote, active and Hybrid islanding detection methods. Section 5 compares different types of IDM based on NDZ, detection time and power quality.

2 Certain Challenges with Islanding

Unintentional islanding into the system leads a big concern since integrated power distribution networks was implemented. Such integrated system together with inverter or non-inverter-based DG systems, different load conditions, and compounded control strategy give rise to many challenge to power system network reliability [7]. There are numerous IDMs presented in research paper, which uses different tolls for effective capacity building, tools name as complex computing and signal analysis [8]. Though, still some problems remain that need to be examined in the field of islanding detection, example as performance of IDMs for concurrent operations, interaction between different DG systems which are fitted with AI devices, when islanding occurs. Tackling mentioned challenges and highlighting the responsiveness of the AI devices, IDMs are analytically analysed in this review. If an island of the power system is created unintentionally, it causes trouble and serious harms. Some of the important harms are discussed as.

- The voltage and frequency may get affected and not remain in their appropriate standard level.
- Line staff safety may be vulnerable by DGs feeding into a system after opening and tagging of primary sources.
- Instant reclosing may cause phase difference. This causes huge torques mechanically and huge difference in current (I) /voltage (V), might shatter the physical systems [9]. Sharp rise leads to devastation of the appliances also.

3 Indices / Parameters of Islanding Detection Methods

The objective of the islanding detection techniques is to monitor certain system parameters such as rate of change of frequency, Voltage, current, ΔP, ΔQ and accordingly determine any possible occurrence of grid disconnection based on the threshold value of the parameters. The salient characteristics of an effective and reliable IDM are listed below:

- Minimum NDZ
- Minimum detection time

- High Power quality (lower value of THD)
- Error detection ratio close to 1 i.e. minimum events of false detection.

Hence, IDMs can be assessed on the basis of four relevant performance indices namely Non detection Zone (NDZ). Detection time (Δt), power quality and error detection ratio (E_d).

3.1 Non Detection Zone (NDZ)

NDZ became the primary cause for failing of IDMs. NDZ methods is build up by observing of V, I and f deviation that lead to power mismatch. Power mismatch between output of DG and load utilization when distributed generator operates in islanding condition are due to fluctuation of V and f at a point of common coupling (PCC). When ΔP and ΔQ are almost to zero, at that time V and f fluctuation are not enough to detect the islanding. The range of power mismatch (ΔP, ΔQ), which can't cause V and f crossing the threshold set value to detect islanding is known non detection zone (NDZ) [6, 10]. NDZ in power mismatch space is shown by [11].

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

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

where [V_{min}, V_{max}] is the allowable voltage range, f_{min} is minimum frequency and f_{max} is maximum frequency, V and P are rated voltage and active power, and Q_f is the quality factor. NDZ region is shown in Fig. 3. NDZ stands "non-detection zone" the range of conditions where a real grid failure will be filtered out.

NDZ is a very useful feature used for evaluating and examining the effectiveness of the islanding detection technique. Figure 3, shows ΔP versus ΔQ plane and this power imbalance happen due to V and f variations. Out of the shaded region AI device sense the islanding condition and thus disconnect the DG but this would not be possible in case of power difference came within power mismatch space and thus it became threat for the safety unit.

3.2 Detection Time

Time interval between the disconnecting of the main grid and detecting islanding b IDMs that is expressed as

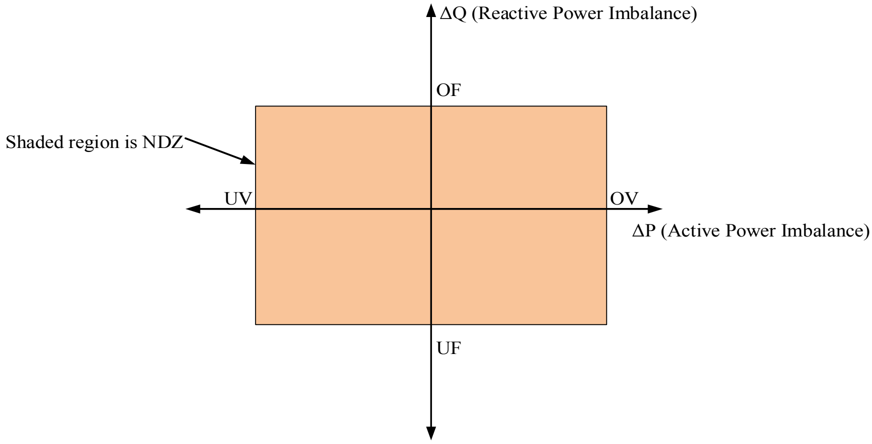

Fig. 3 Power mismatch space or NDZ region

$$\Delta t = t_{IdM} - t_{trip} \tag{3}$$

where Δt is the detection time, t_{IdM} is the instant at which islanding detected and t_{trip} is the instant at which circuit breaker of the main grid get trip and isolate the DGs.

3.3 Power Quality

For the power quality, several aspects have to be taken in consideration like voltage, current and frequency stability as well as continuous supply of power and there waveform. Due to all these concerns it doesn't have the particular definition and thus it is also known as service quality, voltage and current quality but judging the all parameters it can defined as the calculation, analysis, and betterment of the line parameters to maintain a reference waveform.

3.4 Error Detection Ratio

It is related to the false detection of islanding by IDMs whenever utility grid and micro grid (MG) are interconnected. Error measurement caused primarily by disturbance, which results in measured units exceeding the set points [12]. It is described as

$$E_d = \frac{N_{error\ detected}}{N_{error\ detected} + N_{correct\ detected}} \tag{4}$$

where E_d is error detection ratio, $N_{error\,detected}$ is count of time false detection and $N_{correct\,detected}$ is count of time correct detection.

4 Islanding Detection Methods

Various detection methods are being identified the researchers across the world. Typically, these can be classified into remote islanding detection (RID) and local islanding detection (LID) methods. RID methods are based on measurement and calculation of technical parameters at the central side [13–18], while LID methods are based realization at DG side. LID methods can be further divided into passive islanding detection (PID) [19–53], active islanding detection (AID) and hybrid islanding detection (HID) methods as shown in Fig. 2. In this work, Active Islanding [54–64] and Hybrid Islanding techniques [57, 65, 66] are extensively reviewed. Passive detection techniques are discussed in our recent review article [67].

4.1 Active Islanding Detection Methods

In these AID methods, intentionally injecting small perturbation at the output end of the DGs, that injecting signal do some significant changes in the system parameters and if that changes exceed the predefined value then trip signal get activated of the islanding condition and thus DG get disconnected. Remarkably AID methods have advantage as their low or zero NDZ, but major demerit is that these methods deteriorate the power quality. The basic flow chart of AID methods is shown in Fig. 4, and then different AID methods discussed briefly.

4.1.1 Active Frequency Drift (AFD)

Electrical parameters voltage and current are associated with the magnitude, frequency and phase. AFD uses the frequency/phase related parameters. In this method a small disruption current is injected into the main system, and whenever the islanding phenomena occurs, frequency drift take place by adding a zero time in inverter current and make the inverter current waveform distorted with respect to the original waveform i.e., shown in Fig. 5, however it is not affected during the grid connected system. Distortion meaning is phase difference between inverter output waveform (current) and original waveform of utility voltage at PCC. Due to distortion, inverter detect phase error, and participate in drifting the DG/inverter current to make the phase error zero. To make the drift occurs, DG connected inverter should work at unity power factor, and frequency drift is compared with OUF relay for islanding to be detected. For this a parameter is defined name as chopping fraction (cf) shown in Eq. (5).

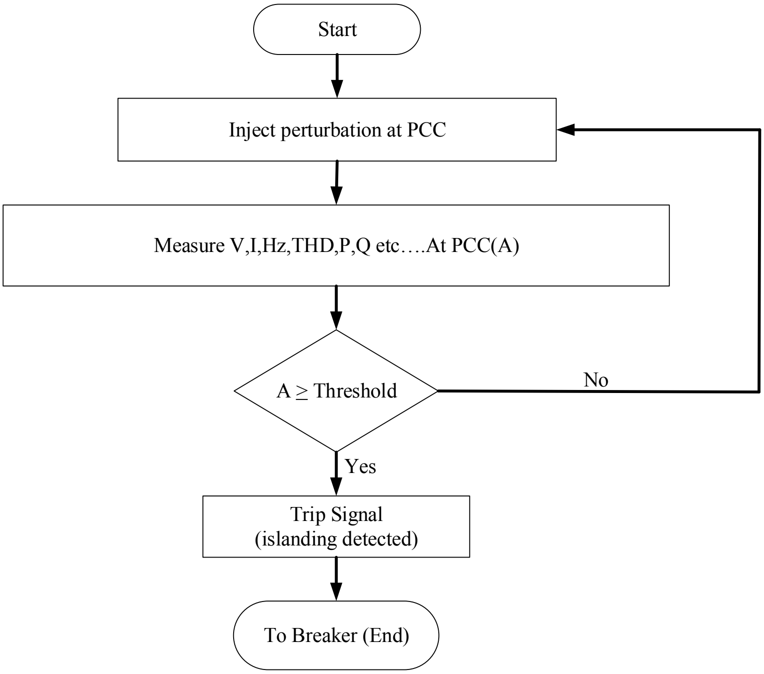

Fig. 4 Flow chart of AID methods

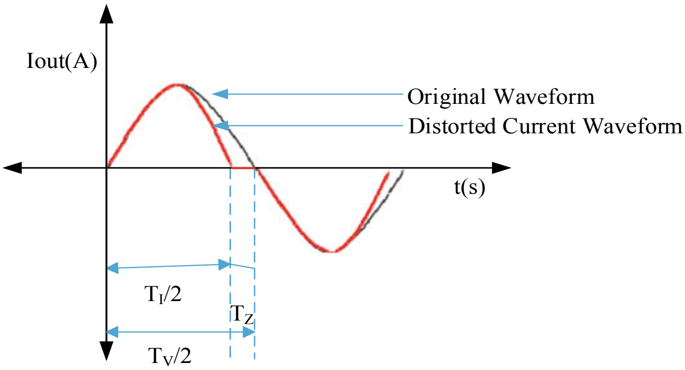

Fig. 5 Operational waveform of AFD method [54]

$$cf = \frac{T_Z}{T_V/2} \tag{5}$$

where, T_Z = zero or dead time and T_V = time period of utility voltage. It is easy in implementation and having small NDZ compare to novel PID methods. Drawbacks are, effective for purely resistive load, as NDZ became large during large values of capacitance (C) and inductance (L), also wouldn't suitable for parallel inverter systems, and have issue with the power quality [54].

4.1.2 Active Frequency Drift with Positive Feedback (AFDPF)

For supressing drawbacks of AFD (multi-inverter and NDZ issue), a positive feedback is used along with AFD. This feedback amplify the chopping fraction (*cf*) or dead time and assist the frequency drift at higher rate. Due to increase in the rate of frequency detection, it leads to detect the islanding condition fastly compared to AFD.

$$cf_K = cf_{K-1} + G(\Delta\omega_k) \tag{6}$$

where cf_K and cf_{K-1} are kth chopping fraction and $(k-1)$th chopping fraction, $\Delta\omega_k$ = frequency difference = $\omega_{K-1} - \omega_0$, G is positive gain constant. No matter *cf* is positive or negative, AFDFP reinforced the frequency drift for any load, but the power quality degradation is still continued due to injected disturbance [55].

4.1.3 Sandia Frequency Shift (SFS)

This method is also an add-on of AFD, using a positive feedback for the frequency of the output voltage at the inverter end, whose chopping fraction is expressed as

$$cf = cf_0 + K(f_{PCC} - f_{line}) \tag{7}$$

where, cf_0 is chopping fraction without frequency variation, K is accelerating gain, f_{PCC} is frequency of voltage at PCC and f_{line} is the frequency of the original line.

During normal operation DG sets try to change the frequency but system stability maintain the same frequency, but during utility grid disconnected mode, there is rise in the frequency attempted at PCC and thus increase the chopping fraction. Whenever the frequency at the inverter end crosses the set value then islanding is detected. SFS method has very small NDZ, as well as detecting efficiency and power quality is improved [56].

4.1.4 Sandia Voltage Shift (SVS)

This method uses the same principle as SFS, just change is that it uses a positive feedback of magnitude of voltage at PCC and changes the current and power. When grid is linked there is no effect shown of this positive feedback, but during open linked voltage is reduced at PCC and thus current and power reduced. For that reduction of voltage a UV relay is used for the protection. Possibility is also of rising of voltage, and hence OUV relay is used, if the PCC voltage reaches OUV standards then islanding is detected [57]. Among all AID methods this method is quite easy in implementation, having small NDZ but facing the problem of power quality issue.

4.1.5 Slip Mode Frequency Shift (SMFS)

Practice is carried out by applying positive feedback to the phase of the PCC voltage. A small perturbation in the phase will cause frequency deviation during the grid disconnected, but a small disturbance in phase during grid connected mode will not lead to frequency deviation, hence phase difference in normal operation is almost zero as unity power factor maintain by the inverter. A SMFS curve Fig. 9, using Eq. (8).

$$\theta_{SMFS}(k) = \theta_m \sin\left(\frac{\pi}{2}\frac{\left(f^{(k-1)} - f_0\right)}{(f_m - f_0)}\right) \quad (8)$$

where θ_m is maximum phase deviation which occur at maximum frequency f_m and $f^{(k-1)}$ is previous cycle frequency and f_0 is rated frequency. Equation (8) is showing the relation between frequency and phase angle. Working principle also validate that slope of the SMFS line is greater than the load line during unstable region. When grid get disconnected, operation will move towards the new stable point (shown by dotted as $f1$ and $f2$), during going through unstable to stable a set threshold value of inverter frequency crossed in either direction and thus islanding get detected by OUF relay. Problem with this method is having large NDZ and quality of power issue [58].

4.1.6 Automatic Phase Drift (APS)

This method is extension of SMFS, used to rectify the problem of NDZ of AFD and SMFS methods by utilizing positive feedback to the phase angle of output current of inverter. Hence only starting angle of inverter current alter consistently by using previous frequency of voltage, expression is shown as

$$\theta_{APS}^{(k)} = \frac{1}{\alpha}\left(\frac{f^{(k-1)} - fo}{fo}\right)360^{\circ} + \theta_0^{(k)} \quad (9)$$

where $\theta_{APS}^{(k)}$ is beginning angle of inverter I, α is constant and $\theta_0^{(k)}$ is additional phase shift induced each time in the terminal voltage.

$$\theta_0^{(k)} - \theta_0^{(k-1)} = \Delta\theta * sgn(\Delta f_s) \quad (10)$$

where $\Delta\theta =$ constant, $\Delta f_s =$ change in steady state frequency, $sgn =$ sign or signum function i.e., defined as:

$$sgn(\Delta f_s) = \begin{cases} 1\ if\ \ f_s > 0 \\ 0\ if\ \ f_s = 0 \\ -1\ if\ \ f_s < 0 \end{cases} \tag{11}$$

Due to additional phase shift, frequency deviate of the voltage to stabilizing to new operating point, and during islanding this deviation of the frequency leads the OUF standards, thus islanding get detected. Disadvantages of this method are speed is slow and not suited for nonlinear load [59].

4.1.7 Variation in Active and Reactive Power

Method is based on the capacity of inverter to produce both active power and reactive power independently. During the utility disconnected mode, DG has to supply active power, and depending upon the load condition, voltage will rise or fall as voltage is related directly to the active power. When the change in the voltage exceeds the set threshold value, then islanding condition is detected by the help of OUV relay.

Similarly reactive power cause frequency variation, and it's detected by the OUF relay. The detection time is around 0.3–0.75 s, easy in implementation and has small NDZ. Weaknesses are it can't support multi-inverter as false detection sometime raised, power quality issue continued [60].

4.1.8 Negative Component of Current Injection (NCCI)

This method is involving the use of small injection of negative component of current (less than 3%) to the voltage source inverter (VSI) at the PCC terminal, leads to disturbing the PCC voltage as unbalancing of the voltage occurs during the grid disconnected. In normal mode NCC flow into grid without affecting the PCC voltage. Thus islanding get detected if negative sequence voltage exceeds the threshold value within 60–70 ms. Method is beneficial for any load, zero NDZ and detecting fast compare to positive sequence voltage [61, 62]. This method can also use to detect islanding by negative sequence impedance as it's the ratio of negative component of voltage and current.

4.1.9 Impedance Measurement (IM)

Ratio of rate of change of voltage (ROCOV) to the rate of change of current (ROCOC) of the inverter gives the impedance. This (dv/di) technique is used for the detection as during normal operation variation in the voltage is very less and hence impedance is low, but during grid disconnected mode voltage varies significantly by perturbation in the current and thus impedance crosses the threshold value and islanding get detected. Detection time is around 700–900 ms [63]. It's advantage is that NDZ is low and work effectively in case of single inverter and synchronously connected multi inverter, but all time synchronously would not be possible and thus multi inverter is became demerit for it.

4.1.10 Impedance Detection at Specific Frequency

This technique is exceptional case of harmonic detection method. A perturbation of the special frequency harmonics of the current are injected in the inverter. Due to this abruptly change occurs in the voltage of inverter placed at PCC terminal when the utility is disconnected, but not significant change during utility connected to the DGs. Due to production of harmonic voltage in the system, impedance can be measure and if it crosses more than the set point, then islanding detected. It is not appropriate for the multi inverter system [64].

4.2 Hybrid Islanding Detection Methods

As passive and active methods are suffering from large NDZ and power quality issue respectively. To eradicate both the problems, a HID methods are used, that combine both PID and AID methods. In this case AID methods apply after the use of the PID methods as shown in the flow chart of Fig. 6. Some of the HID methods are discussed in brief as the following.

4.2.1 Voltage Unbalance (VU) and Frequency Set Point

As VU (passive) is more sensitive to the load fluctuation, so instead of VU/THD (passive), this method uses VU as a passive parameter. Other active parameter should be needed that is completed by positive feedback to the voltage or current that leads to deviation in the frequency by using SFS/SVS. Whenever some changes in the system occur the voltage spike rises suddenly, and from precaution of the false detection due to load switching or transient, a maximum VU is set for their threshold i.e., around 35 times of the VU average as per the Menon and Nehrir proposal [65]. Voltage spike also leads to frequency deviation, if the frequency change in a specified time is greater than the threshold value then islanding condition get detected. Technique have advantages as very small NDZ, very low power quality issue and clearly discriminate islanding and non-islanding conditions.

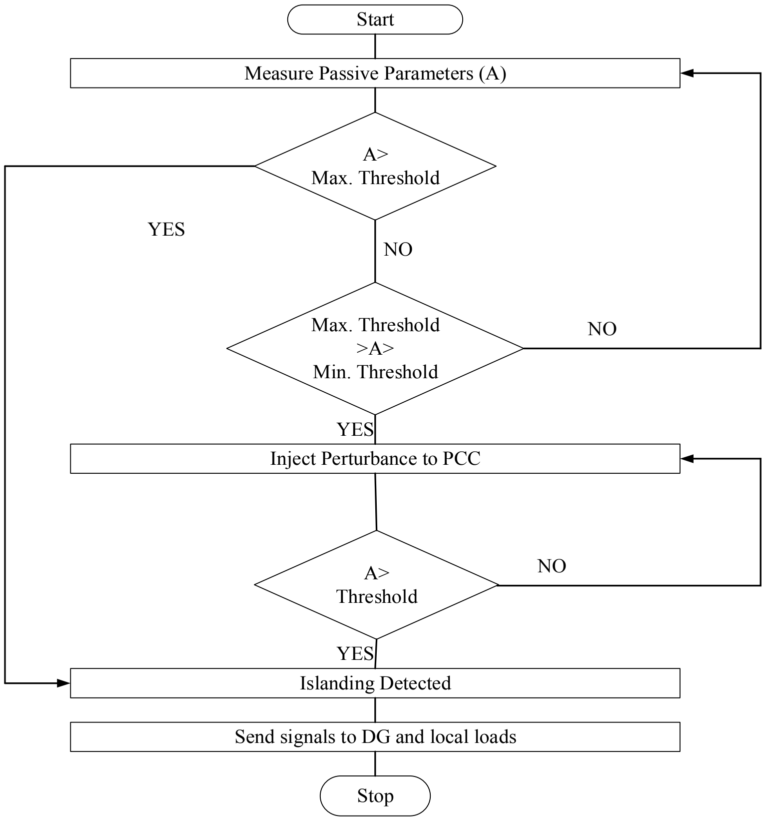

Fig. 6 Flow chart of HID methods

4.2.2 Voltage Fluctuation Injection

This method consist of ROCOF/ROCOV (passive) and chopping fraction, CF (active) method. As shown in the HID flow chart, if the rate of change of F/V is greater than the large (maximum) setting value of threshold then islanding is confirmed directly, and when the ROCOF/V is greater than the small (minimum) setting value of threshold then immediately AID method get activated [57]. In AID chopping frequency (CF) is checked, and if CF value is also more to their corresponding threshold value then islanding detected, otherwise it would be considered as non-islanding case.

4.2.3 SFS and Q-f (ROCOF) Technique

This method is based on the integration of the Sandia frequency shift, SFS (active) and ROCOF (passive) technique [66]. For large power variation, islanding confirmed directly by ROCOF method only, but if the variation is in between the large and small then active method (SFS) will come into the action and by perturbation the islanding can be detected. Similarly many HID methods (like ROCOV and P, ROCOF and IM, ROCOF and frequency injection) can be formed by implementing the integrated passive and active IDMs.

5 Comparison of IDMs

Key technical factors such as (NDZ), detection time and power quality were considered for comparing RID, PID, AID and HID methods. A fair comparison of widely adopted IDMs has been presented in in Table 2. Each method has its own pros and cons which are listed in Table 3. Selection of IDMs are dependent on number of factors such as system power rating, network loading conditions, cost effectiveness, protection devices and integration guidelines and allowable limits. In terms of cost, PID has advantages over the others. RID requires high initial and maintenance costs.

6 System Architecture of a Grid Connected Solar Based DG

Figure 7 shows a Solar photovoltaic based DG connected to the 110 kV Utility grid. A DC-DC boost converter stabilizes the output of the PV arrays at a constant DC voltage of 500 V. A 3 level DC/AC power converter is used to process the power to the local loads and the main grid. CB1 and CB2 are the breakers for 20 and 110 kV bus respectively. Two local loads are connected to 20 kV feeder. Five different islanding detections methods are modelled to provide a trip signal during islanding events. They are Over/Under Voltage IDM, Over/Under Current IDM, Over/Under Frequency IDM, modified ROCOF IDM and Vector Shift IDM.

7 Results and Discussion

Five different IDMs are modelled and tested on a grid connected Solar photovoltaic based Distributed Generation system in MATLAB/SIMULINK environment. The PV inverter is connected to a 20 kV Bus through a 3-Φ 100 kVA Δ/Y transformer. Circuit breaker CB1 connects the two local loads to the 20 kV Bus. The DG units and local loads are connected to 110 kV, 2500 MVA, 50 Hz Utility Grid through a circuit breaker CB2. Islanding event is achieved by opening CB2 at $t = 0.1$ s. Unintentional islanding usually pose power quality issues when the local generation capacity is adequately not enough to supply the local consumer demands. Hence, two loading scenarios have been considered for the simulation study. Trip Signal is generated on successful detection of islanding event in two cases described below:

Table 2 Technical comparison of different IDMs based on three key performance metrics

Method's name (RID)	NDZ	Δt (ms)	PQ
PLC	Nil	200	No effect
TT	Nil	–	No effect
SCADA	Nil	Slow speed in busy grid	No effect
Method's name (PID)	NDZ	Δt(ms)	PQ
OUV/OUF	Large	4 to 2000	No effect
ROCOF	Large	24	No effect
ROCOP	<than OUV/OUF	>One cycle	No effect
ROCOFOP	<ROCOF	100	No effect
ROCOFORP	Very small	–	No effect
PJD	Large	10–20	No effect
VU	Large	53	No effect
THD (V/I)	Large, (Q high)	45	No effect
VU AND THD	Small	25 to 2000	No effect
ROCOV and CPF	Small	35	No effect
ROCONSV (ac)	Nil	80	No effect
ROCOPSV (ac)	Nil	10	No effect
ROCO (PSV and PSC)	Nil	10	No effect
ROCOEVORP	Nil	–	No effect
ROCOEV with CBSS	Nil	100 to 300	No effect
PANSVNSC	Nil	Within 4.16	No effect
FHO	Very small	Upto 440	No effect
Method's name (AID)	NDZ	Δt (ms)	PQ
AFD	Very small	Within 2000	Degrade
AFDPF	Very small	<AFD	Slight degrade
SFS	Very small	500	Degrade
SVS	Small	–	Slight degrade
SMFS	<AFD	400	Spike in system
APS	Small	Small	Degrade
NCCI	Zero	60	–
IM	Small	700–900	Slight degrade
Method's name (HID)	NDZ	Δt (ms)	PQ
VU and SFS/SVS	Very small	–	Slight degrade
ROCOV and P	Small	Within 2000	Slight degrade
ROCOF and IM	Small	216	

Table 3 Merits and Demerits of Different Islanding Detection Methods

Islanding detection methods	Merits	Demerits
Remote islanding methods (RID)	• Highly reliable	• Quiet expensive especially for low-medium power Microgrid
Passive islanding methods (PID)	• Lower detection time • Does not disturb the system • Reliable in extreme loading conditions	• Less effective in low loading conditions • Requires attention while deciding the threshold levels
Active islanding methods (AID)	• Reliable even when generation matches the demand • Small NDZ	• Perturbs the system • Slow response • System stability may disturb under perturbations
Hybrid islanding methods (HID)	• Injects disturbances only when islanding is suspected • Smaller NDZ • Power quality better than active islanding case	• Detection time is more

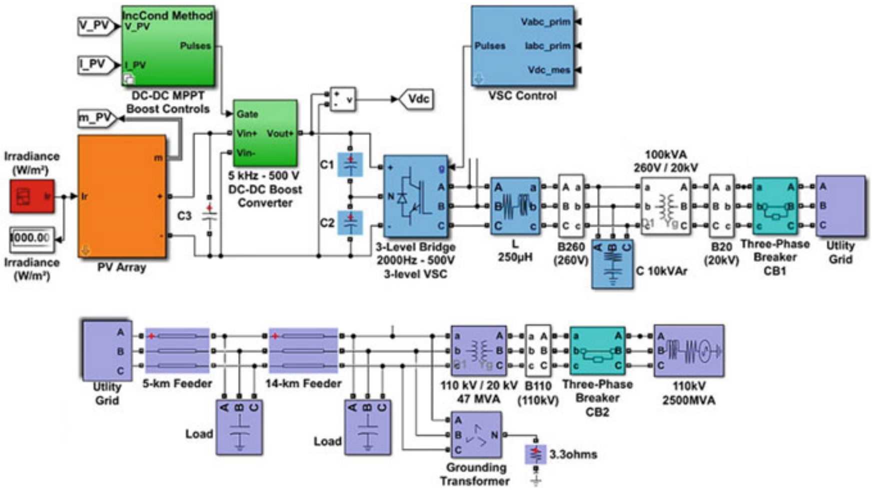

Fig. 7 Grid connected solar photovoltaic based DG under study

- Local generating capacity is either equal to the local load requirement
- Local generating capacity is less than the local load requirement

In this study, Over/Under voltage, Over/Under current, Over/Under Frequency, modified ROCOF and vector shift methods are examined.

7.1 *Case 1: Local Load is Equal to Local Generation*

This test is performed at the 20 kV feeder where local loads are connected. Load 1 and Load 2 demands 50 kW each.

For the performing the islanding test, circuit breaker (CB2) of the main grid is opened at the instant of 0.1 s and reclose at instant of 0.25 s. Within the time interval of CB2 open condition (islanding condition) many parameters are changed, and if any parameters are crossed the corresponding threshold value then trip signal is generated for the removal of DG.

As seen in Fig. 8, when the islanding events occurred, suddenly voltage and current parameters are affected. In Fig. 9 change of frequency and modified ROCOF are observed. RMS Value of Phase voltages can be observed in Fig. 10. Trip signal is generated when the selected parameters crosses the set threshold values. Islanding is detected by OUV, OUC, OUF, m-ROCOF and VS within 10 m, 15 ms, 65 ms, 25 ms and 25 ms respectively as shown in Fig. 11. During reclosing of the load at 0.25 s, a transient is seen which is suppressed within few cycles.

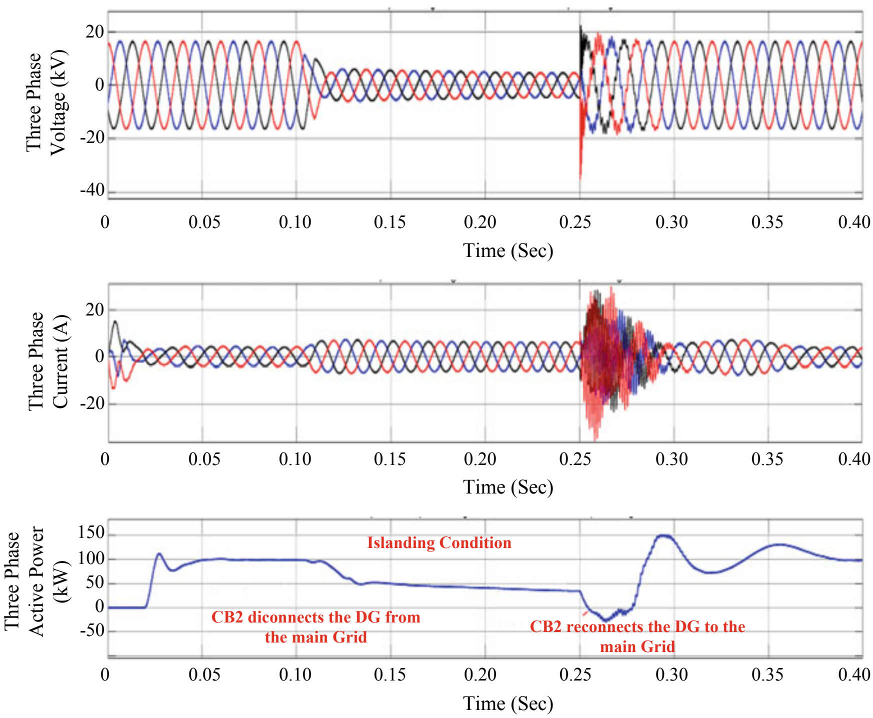

Fig. 8 Variation of three phase voltage, current and active power in case local load equals PV generation

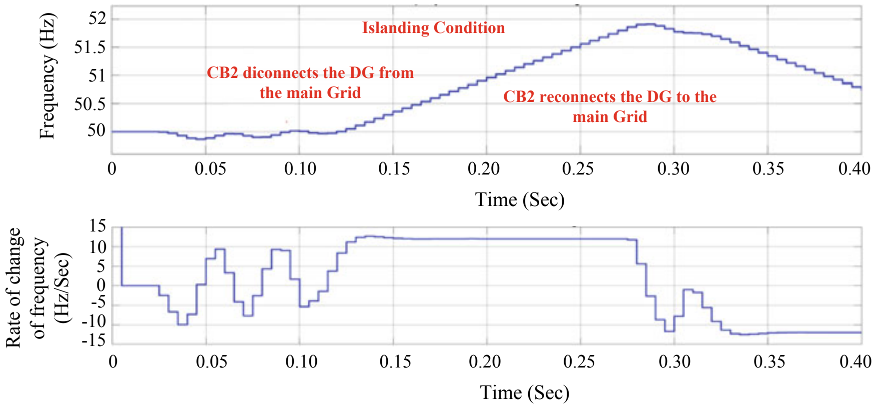

Fig. 9 Variation of frequency (50 Hz), and ROCOF in case local load equals PV generation

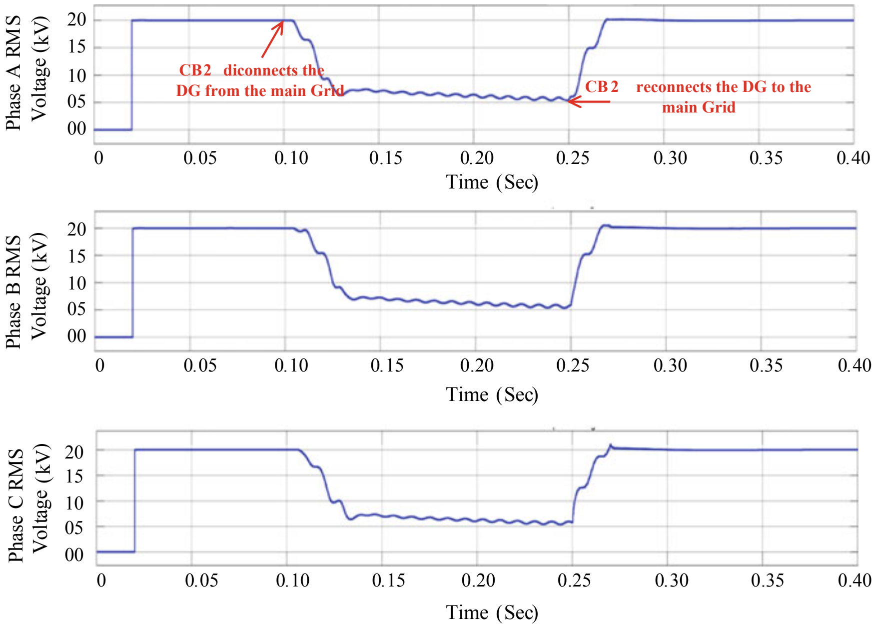

Fig. 10 Variation of Variation in RMS value of voltage Va, Vb and Vc in case local load equals PV generation

7.2 Case 2: Local Load Exceeds Local Generation

This test is also performed at the 20 kV feeder where local load are connected as per the specification: load 1 requires 2 MW and load 2 requires 30 MW and 2 MVAR (lagging) respectively. For performing the islanding test CB2of the main

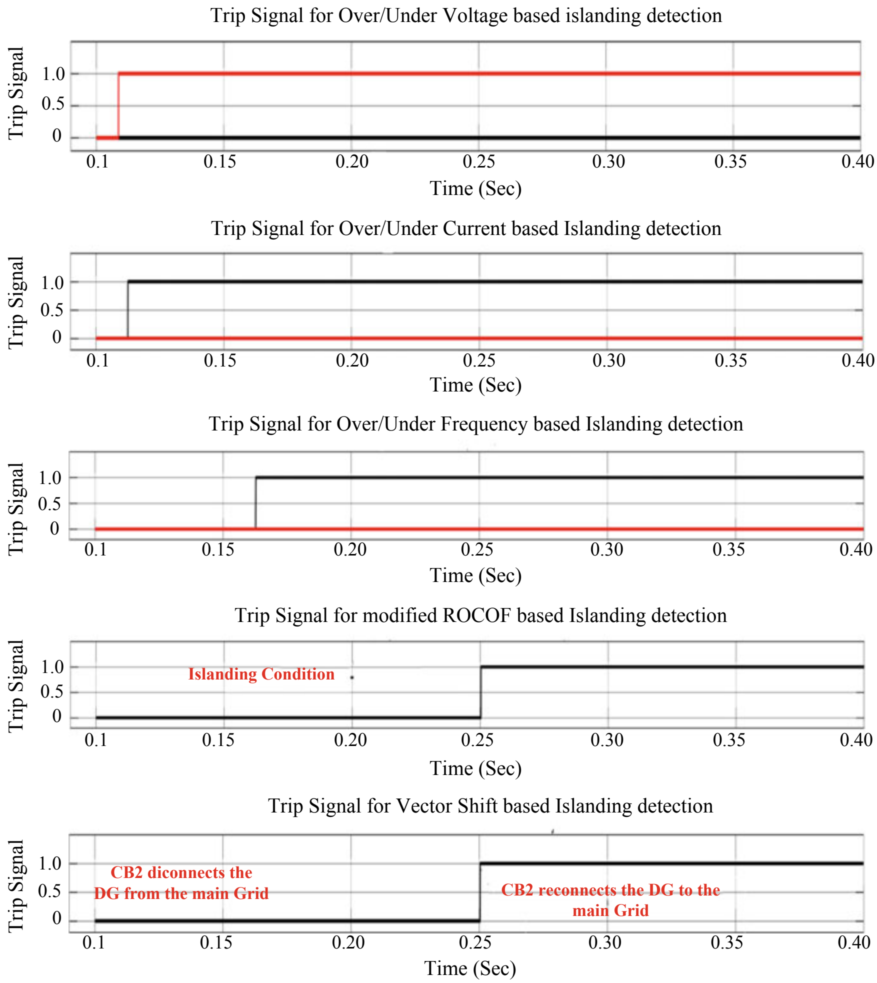

Fig. 11 Islanding detection (trip signal) in case local load equals PV generation

grid is opened for some time i.e., from 0.1 to 0.25 s. Within this period, electrical parameters crosses the set threshold value then islanding get realized. In Fig. 12, during islanding events, sudden change of voltage and current magnitude is seen, and the change crosses the threshold value, hence islanding get detected. The detection time of the OUV is around 7 ms, while detection time of over/under current is around 12 ms, i.e., the fast detection corresponding to the previous case discussed. Variation in active power is also shown in Fig. 12, i.e., sudden dip of power during islanding event. PV based DG is unable to supply the load resulting in load shedding.

In Fig. 13 change of frequency and modified ROCOF are seen and islanding is detected with the corresponding detection time as 54 ms and 65 ms respectively. RMS value of Phase voltages can be observed in Fig. 14. A vector shift is also detected

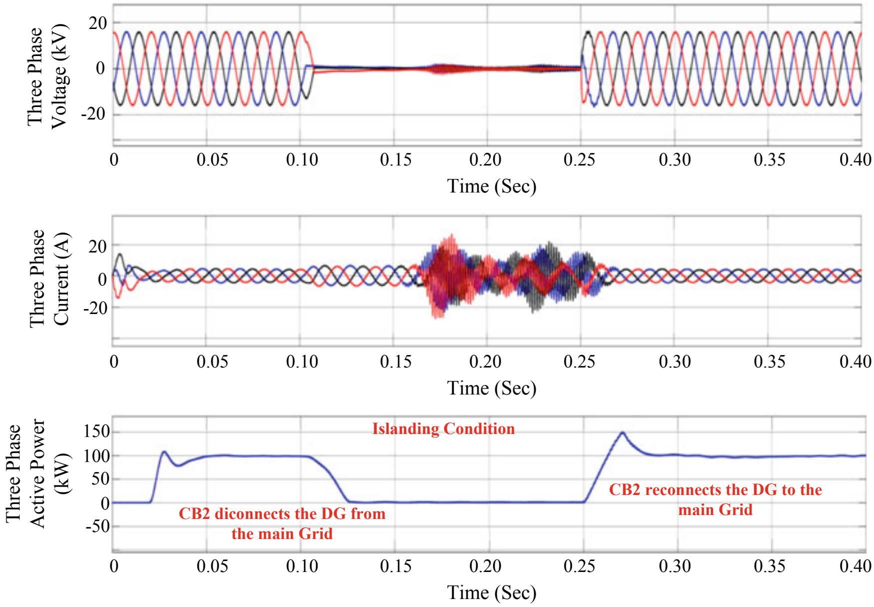

Fig. 12 Variation of three phase voltage, current and active power in case local load exceeds PV generation

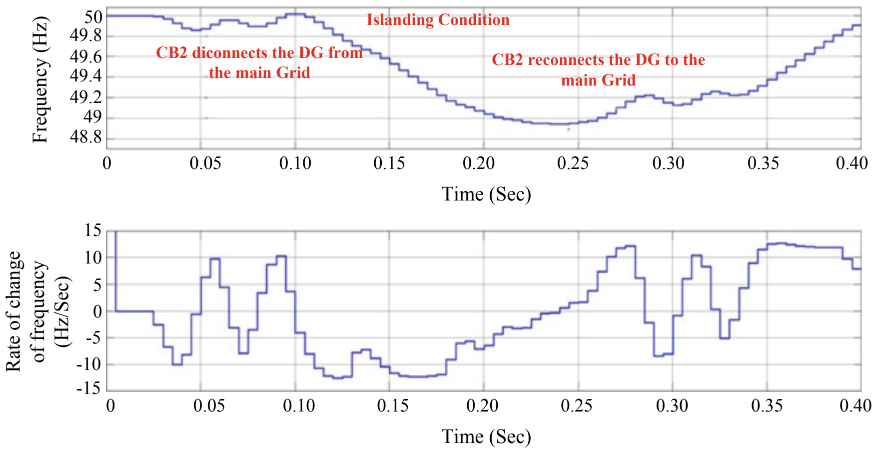

Fig. 13 Variation of frequency (50 Hz), and modified ROCOF in case local load exceeds PV generation

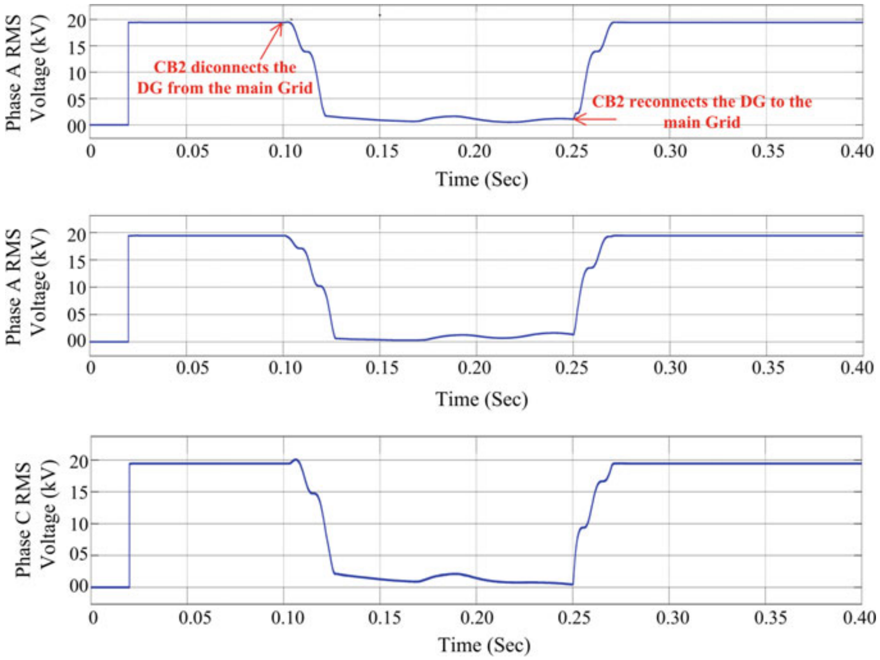

Fig. 14 Variation in RMS value of voltage Va, Vb and Vc in case local load exceeds PV generation

having the detection time is equal to 64 ms. Trip signals are generated on successful islanding detection using OUV, OUC, OUF, m-ROCOF and VS as shown in Fig. 15.

Out of these five, three methods OUV, over/under current and OUF are based on the magnitude comparison of voltage, current and frequency. It is observed that the fast detection is done by OUV and followed by over/under current but problem with these are having large false detection. So, further methods modified ROCOF and voltage vector shift are observed and found that, it eliminate the false detection condition to somehow. Hence, accuracy is improved in both methods as two passive parameters are checked there and hence detection time increased. Detection time and non-islanding conditions are discussed in Table 4.

8 Conclusion

In this paper, active islanding detection techniques have been described for the utility connected micro grid system. The IDMs comparison is based on standards listed in Table 1, mainly IEEE 1547. Remote methods requires noise free, efficient and faster communication infrastructure, and hence the cost is high but is most reliable, as NDZs are minimized and prevents degradation of power quality. An active method has very small NDZ but degrade the power quality and that is why hybrid methods come into

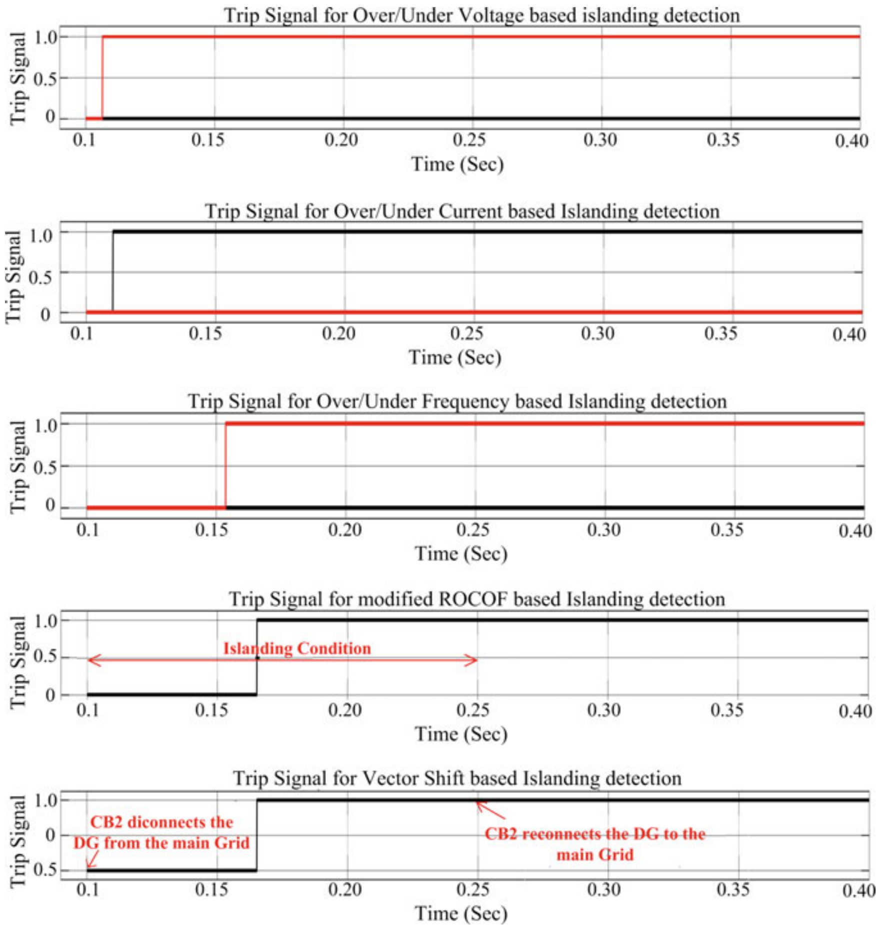

Fig. 15 Islanding detection (trip signal) in case local load exceeds PV generation

Table 4 Islanding detection time for each IDM

Technique's name	$t_{detection}$ (ms) Case 1	$t_{detection}$ (ms) Case 2
OUV	10	1
Over/under current	15	12
OUF	62	54
Modified ROCOF	150	65
Voltage vector shift	150	54

the picture to eradicate the high NDZ of passive and power quality issue of active, by combining the both methods (passive and active), detection time became prolonged. Generally passive detection time is low compared to both active (for seeing the response after perturbation, needed somehow more time) and hybrid. After being easy installation and lesser cost of PID methods, still it is not chosen because of their limitation with multi inverter systems and NDZ during balance islanding. In most of the cases AID are being used, but future trend will be hybrid and RID as both giving the good result over islanding and non-islanding, and capable of use of multi inverter systems with good reliability. Hence, this literature is providing a good concept over islanding detection, and it will be helpful for the future research. A grid connected architecture of a Solar based Distributed generation system is examined under islanding events using five IDMs. Modified ROCOF and voltage vector shift are observed to be more effective than conventional under/over voltage, current and frequency detections as they eliminates false detection conditions.

References

1. Dutta S, Sadhu PK, Reddy MJB, Mohanta DK (2018) Shifting of research trends in islanding detection method—a comprehensive survey. Protect Control Modern Power Syst 3(1). https://doi.org/10.1186/s41601-017-0075-8
2. Acharya N, Mahat P, Mithulananthan N (2006) An analytical approach for DG allocation in primary distribution network. Int J Electr Power Energy Syst 28:669–678. https://doi.org/10.1016/j.ijepes.2006.02.013
3. Chiang WJ, Jou HL, Wu JC (2012) Active islanding detection method for inverter-based distribution generation power system. Int J Electr Power Energy Syst 42(1):158–166. https://doi.org/10.1016/j.ijepes.2012.03.038
4. Basso TS (2014) IEEE 1547 and 2030 standards for distributed energy resources interconnection and interoperability with the electricity grid. National Renewable Energy Laboratory, Golden, CO, USA, vol 15013. https://doi.org/10.2172/1166677
5. Reddy CR, Reddy KH (2019) Islanding detection techniques for grid integrated DG—a review. Int J Renew Energy Res 9(2):960–977
6. Li C, Cao C, Cao Y, Kuang Y, Fang B (2014) A review of islanding detection methods for microgrid. Renew Sustain Energy Rev 35:211–220. https://doi.org/10.1016/j.rser.2014.04.026
7. Vahedi H, Noroozian R, Jalilvand A, Gharehpetian GB (2011) A new method for islanding detection of inverter-based distributed generation using DC-link voltage control. IEEE Trans Power Deliv 26:1176–1186. https://doi.org/10.1109/TPWRD.2010.2093543
8. Khamis A, Xu Y, Dong ZY, Zhang R (2018) Faster detection of microgrid islanding events using an adaptive ensemble classifier. IEEE Trans Smart Grid 9:1889–1899. https://doi.org/10.1109/TSG.2016.2601656
9. Walling RA, Miller NW (2002) Distributed generation islanding implications on power system dynamic performance. IEEE Power Eng Soc Summer Meeting 1:92–96. https://doi.org/10.1109/PESS.2002.1043183
10. Bahrani B, Karimi H, Iravani R (2011) Non-detection zone assessment of an active islanding detection method and its experimental evaluation. IEEE Trans Power Deliv 26(2):517–525. https://doi.org/10.1109/TPWRD.2009.2036016
11. Ye Z, Kolwalkar A, Zhang Y, Du P, Walling R (2004) Evaluation of anti-islanding schemes based on nondetection zone concept. IEEE Trans Power Electron 19(5):1171–1176. https://doi.org/10.1109/TPEL.2004.833436

12. Vieira JCM, Salles D, Freitas W (2011) Power imbalance application region method for distributed synchronous generator anti-islanding protection design and evaluation. Electr Power Syst Res 81(10):1925–1960. https://doi.org/10.1016/j.epsr.2011.06.009
13. Mahat P, Chen Z, Bak-Jensen B (2008) Review of islanding detection methods for distributed generation. In: Third international conference on electric utility deregulation and restructuring and power technologies, pp 2743–2748. https://doi.org/10.1109/DRPT.2008.4523877
14. Rumbayan M (2017) Development of power system infrastructure model for the island communities: a case study in a remote island of Indonesia. In: International conference on advanced mechatronic systems, pp 515–518. https://doi.org/10.1109/ICAMechS.2017.8316470
15. Wang W, Kliber J, Zhang G, Xu W, Howell B, Palladino T (2007) A power line signaling based scheme for anti-islanding protection of distributed generators: Part II: field test results. IEEE Trans Power Deliv 22:1767–1772. https://doi.org/10.1109/TPWRD.2007.899620
16. Raza S, Mokhlis H, Arof H, Laghari JA, Wang L (2015) Application of signal processing techniques for islanding detection of distributed generation in distribution network: a review. Energy Convers Manage 96:613–624. https://doi.org/10.1016/j.enconman.2015.03.029
17. Kim MS, Haider R, Cho GJ, Kim CH, Won CY, Chai JS (2019) Comprehensive review of islanding detection methods for distributed generation systems. Energies 12(5):837. https://doi.org/10.3390/en12050837
18. Xiao H, Fang Z, Li C, Xu D, Venkatesh B, Singh BN (2017) Anti islanding protection relay for medium voltage feeder with distributed generator. IEEE Trans Ind Electron 64(10):7874–7885. https://doi.org/10.1109/TIE.2017.2694394
19. Guha B, Haddad RJ, Kalaani Y (2015) A novel passive islanding detection technique for converter based distributed generation systems. In: IEEE power & energy society innovative smart grid technologies conference, pp 1–5. https://doi.org/10.1109/ISGT.2015.7131907
20. Zhao J, Zhang D, He J (2017) A passive islanding detection method based on interharmonic impedance. In: IEEE conference on energy internet and energy system integration, pp 1–6. https://doi.org/10.1109/EI2.2017.8245574
21. IEEE 929 (2000) IEEE recommended practice for grid interface of photovoltaic (PV) systems. Institute of Electrical and Electronics Engineers, New York. https://doi.org/10.1109/IEEESTD.2000.91304
22. Timbus A, Oudalov A, Ho CN (2010). Islanding detection in smart grids. In: 2010 IEEE energy conversion congress and exposition, pp 3631–3637. https://doi.org/10.1109/ECCE.2010.5618306
23. Jones RA, Sims TR, Imece AF (1990) Investigation of potential islanding of a self-commutated static power converter in photovoltaic systems. IEEE Trans Energy Convers 5(4):624–631. https://doi.org/10.1109/60.63131
24. Gupta P, Bhatia RS, Jain DK (2016) Active ROCOF relay for islanding detection. IEEE Trans Power Delivery 32(1):420–429. https://doi.org/10.1109/TPWRD.2016.2540723
25. Warin J, Allen WH (1990) Loss of mains protection. In: ERA conference on circuit protection for industrial and commercial installations, pp 4–3
26. Guha B, Haddad RJ, Kalaani Y (2015) A passive islanding detection approach for inverter-based distributed generation using rate of change of frequency analysis. In: IEEE South east conference, pp 1–6. https://doi.org/10.1109/SECON.2015.7133024
27. Ahmad KNEK, Selvaraj J, Rahim NA (2013) A review of the islanding detection methods in grid-connected PV inverters. Renew Sustain Energy Rev 21:756–766. https://doi.org/10.1016/j.rser.2013.01.018
28. Aghdam HN, Ghadimi N, Farhadi P, Hashemi F, Ghadimi R (2011) Detecting the anti-islanding protection based on combined changes of active and reactive output powers of distributed generations. In: 3rd international conference on computer research and development, Shanghai, pp 285–289. https://doi.org/10.1109/ICCRD.2011.5764196
29. Reddy CR, Reddy KH (2017) Islanding detection method for inverter based distributed generation based on combined changes of ROCOAP and ROCORP. Int J Pure Appl Math 117(19):433–440

30. Menon D, Antony A (2016) Islanding detection technique of distribution generation system. In: International conference on circuit, power and computing technologies, pp 1–5. https://doi.org/10.1109/ICCPCT.2016.7530126
31. Nikolovski S, Baghaee HR, Mlakic D (2019) Islanding detection of synchronous generator-based DGs using rate of change of reactive power. IEEE Syst J 13(4):4344–4354. https://doi.org/10.1109/JSYST.2018.2889981
32. Raza S, Mokhlis H, Arof H, Mohamad H, Laghari JA (2016) Prioritization of different passive parameters for islanding detection on the basis of response analysis. In: IEEE international conference on power and energy, pp 615–619. https://doi.org/10.1109/PECON.2016.7951634
33. Raza S, Mokhlis H, Arof H, Laghari JA, Mohamad H (2016) A sensitivity analysis of different power system parameters on islanding detection. IEEE Trans Sustain Energy 7(2):461–470. https://doi.org/10.1109/TSTE.2015.2499781
34. Hu W, Sun Y (2009) A compound scheme of islanding detection according to inverter. In: Asia-Pacific power and energy engineering conference, pp 1–4. https://doi.org/10.1109/APPEEC.2009.4918040
35. Khichar S, Lalwani M (2018) An analytical survey of the islanding detection techniques of distributed generation systems. Technol Econ Smart Grids Sustain Energy 3(10). https://doi.org/10.1007/s40866-018-0041-1
36. Singam B, Hui LY (2006) Assessing SMS and PJD schemes of anti-islanding with varying quality factor. In: IEEE international power and energy conference, pp 196–201. https://doi.org/10.1109/PECON.2006.346645
37. Mahat P, Chen Z, Bak-Jensen B (2011) Review on islanding operation of distribution system with distributed generation. In: IEEE power and energy society general meeting, pp 1–8. https://doi.org/10.1109/PES.2011.6039299
38. Jang S, Kim KH (2004) An islanding detection method for distributed generations using voltage unbalance and total harmonic distortion of current. IEEE Trans Power Deliv 19(2):745–752. https://doi.org/10.1109/TPWRD.2003.822964
39. Tzelepis D, Dyśko A, Booth C (2016) Performance of loss-of-mains detection in multi-generator power islands. In: 13th International conference on development in power system protection, pp 1–6. https://doi.org/10.1049/cp.2016.0066
40. Jose BK, Vincent G (2017) Harmonic current based islanding detection for grid connected PV systems. In: 2017 IEEE international conference on circuits and systems, pp 191–195. https://doi.org/10.1109/ICCS1.2017.8325988
41. Zeineldin HH, Kirtley JH (2009) A simple technique for islanding detection with negligible nondetection zone. IEEE Trans Power Deliv 24(2):779–786. https://doi.org/10.1109/TPWRD.2009.2013382
42. Laaksonen H (2012) New multi-criteria-based algorithm for islanding detection in smart grids. In: 3rd IEEE PES innovative smart grid technologies, pp 1–8. https://doi.org/10.1109/ISGTEurope.2012.6465661
43. Danandeh A, Seyedi H, Babaei E (2012) Islanding detection using combined algorithm based on rate of change of reactive power and current THD techniques. In: Asia-Pacific power and energy engineering conference, pp 1–4. https://doi.org/10.1109/APPEEC.2012.630746
44. Jun L, Liang HX, Xiao-Hu C, Miao X, Wen X (2010) Two islanding detection circuits based on the impedance variation for the micro-grid. In: The 2nd international symposium on power electronics for distributed generation systems, pp 859–863. https://doi.org/10.1109/PEDG.2010.5545813
45. Salman SK, King DJ, Weller G (2001) New loss of mains detection algorithm for embedded generation using rate of change of voltage and changes in power factors. In: International conference on developments in power system protection, pp 82–85. https://doi.org/10.1049/cp:20010105
46. Kumar KM, Naresh M, Singh NK, Singh AK (2016) A passive islanding detection approach for distributed generation using rate of change of negative sequence voltage and current. In: IEEE international conference on electrical, computer and electronics engineering, pp 356–360. https://doi.org/10.1109/UPCON.2016.7894679

47. Rostami A, Jalilian A, Naderi SB, Negnevitsky M, Davari P, Blaabjerg F (2017) A novel passive islanding detection scheme for distributed generations based on rate of change of positive sequence component of voltage and current. In: Australasian universities power engineering conference, pp 1–5. https://doi.org/10.1109/AUPEC.2017.8282394
48. Reddy CR, Reddy KH (2018) An efficient passive islanding detection method for integrated DG system with zero NDZ. Int J Renew Energy Res 8:1994–2002
49. Rostami A, Bagheri M, Naderi SB, Negnevitsky M, Jalilian A, Blaabjerg F (2017) A novel islanding detection scheme for synchronous distributed generation using rate of change of exciter voltage over reactive power at DG-Side. In: Australasian universities power engineering conference, pp 1–5. https://doi.org/10.1109/AUPEC.2017.8282417
50. Naveen G, Reddy KH, Reddy CR, Ramakrishna B, Bramaramba P, Reddy LB (2018) Passive islanding detection method for integrated DG system with balanced islanding. Int J Pure Appl Math 120(06):4041–4058
51. Rostami A, Jalilian A, Hagh MT, Muttaqi KM, Olamaei J (2018) Islanding detection of distributed generation based on rate of change of exciter voltage with circuit breaker switching strategy. IEEE Trans Ind Appl 55(1):954–963. https://doi.org/10.1109/IAS.2017.8101799
52. Bashir J, Jena P, Pradhan AK (2014) Islanding detection of a distributed generation system using angle between negative sequence voltage and current. In: 18th National power systems conference, pp 1–5. https://doi.org/10.1109/NPSC.2014.7103855
53. Bakhshi M, Noroozian R, Gharehpetian GB (2017) Novel islanding detection method for multiple DGs based on forced helmholtz oscillator. IEEE Trans Smart Grid 9(6):6448–6460. https://doi.org/10.1109/TSG.2017.2712768
54. Sundar DJ, Kumaran MS (2015) A comparative review of islanding detection schemes in distributed generation systems. Int J Renew Energy Res 5(4):1016–1023
55. Reis MV, Villalva MG, Barros TA, Moreira AB, Ruppert E (2015) Active frequency drift with positive feedback anti-islanding method for a single phase two-stage grid-tied photovoltaic system. In: 13th Brazilian power electronics conference and 1st southern power electronics conference, pp 1–6. https://doi.org/10.1109/COBEP.2015.7420121
56. Zeineldin HH, Kennedy S (2009) Sandia frequency-shift parameter selection to eliminate nondetection zones. IEEE Trans Power Deliv 24(1):486–487. https://doi.org/10.1109/TPWRD.2008.2005362
57. Khamis A, Shareef H, Bizkevelci E, Khatib T (2013) A review of islanding detection techniques for renewable distributed generation systems. Renew Sustain Energy Rev 28:483–493. https://doi.org/10.1016/j.rser.2013.08.025
58. Akhlaghi S, Akhlaghi A, Ghadimi AA (2016) Performance analysis of the Slip mode frequency shift islanding detection method under different inverter interface control strategies. In: IEEE power and energy conference, pp 1–7. https://doi.org/10.1109/PECI.2016.7459250
59. Hung GK, Chang CC, Chen CL (2003) Automatic phase-shift method for islanding detection of grid-connected photovoltaic inverters. IEEE Trans Energy Convers 18(1):169–173. https://doi.org/10.1109/TEC.2002.808412
60. De Mango F, Liserre M, Dell' Aquila A (2006) Overview of anti-islanding algorithms for pv systems. Part II: active methods. In: 12th international power electronics and motion control conference, pp 1884–1889. https://doi.org/10.1109/EPEPEMC.2006.4778680
61. Alsharidah M, Ahmed NA, Alothman AK (2014) Negative sequence injection for islanding detection of grid interconnected distributed generators. In: IEEE electrical power and energy conference, pp 267–274. https://doi.org/10.1109/EPEC.2014.38
62. Karimi H, Yazdani A, Iravani R (2008) Negative-sequence current injection for fast islanding detection of a distributed resource unit. IEEE Trans Power Electron 23(1):298–307. https://doi.org/10.1109/TPEL.2007.911774
63. Nale R, Biswal M (2017) Comparative assessment of passive islanding detection techniques for microgrid. In: Innovations in information, embedded and communication systems, pp 1–5. https://doi.org/10.1109/ICIIECS.2017.8275935
64. PVPS I (2002) Evaluation of islanding detection methods for photovoltaic utility-interactive power systems. Report IEA PVPS T5-09

65. Menon V, Nehrir MH (2007) A hybrid islanding detection technique using voltage unbalance and frequency set point. IEEE Trans Power Syst 22(1):442–448. https://doi.org/10.1109/TPWRS.2006.887892
66. Khodaparastan M, Vahedi H, Khazaeli F, Oraee H (2017) A novel hybrid islanding detection method for inverter-based DGs using SFS and ROCOF. IEEE Trans Power Deliv 32(5):2162–2170. https://doi.org/10.1109/TPWRD.2015.2406577
67. Shastri R, Samadhiya A, Namrata K (2021) A comprehensive review of remote and passive IDMs of utility grid integrated MG system—Part I. In: Lecture Notes in Electrical Engineering, vol 699, pp 485–496. https://doi.org/10.1007/978-981-15-7994-3_45