ANALYTICAL STUDY OF DIFFERENT TECHNIQUES FOR ISLANDING DETECTION OF PV GRID-TIED SYSTEM

Satyajit S. Chopade[1], Dr. (Mrs.) S. P. Muley[2]

[1]Student, M.Tech., Priyadarshini College of Engineering, Hingna, Nagpur.
[2]Professor, Priyadarshini College of Engineering, Hingna, Nagpur.

Abstract - *Photovoltaic (PV) system is one of the popular choices among the non-conventional energy sources & it has too many advantages over the other energy production system. Specifically, it provides a free and abundant supply of electric energy. The issue of islanding in grid-tied PV systems remains a great challenge to fulfill the required guaranteed security of the PV system technique & the prompt and reliable power supply. Due to islanding, the power supply was interrupted and unwanted hazardous conditions may occur for the PV system equipment. To deal with this type of concern, many islanding detection methods are proposed in the literature, and each of them claims high efficiency, accuracy & better reliability this paper scrutinizes recent islanding detection techniques for PV grid-tied systems in the terms of their merits, viability, effectiveness, and feasibility.*
It helps to identify the most accurate technique & fair comparison from different aspects.

Key Words: Islanding detection, PV system, NDZ, Protection, Review.

1.INTRODUCTION

The past few years have witnessed the PV system being increasingly contributing to energy production all over the world. The integration of new technologies into the actual power grids turns into smart grids. Capable of responding to different changes and requirements for the long term. Those grid-tied PV systems are required to detect any harmful faults to protect the system and load side equipment and ensure the safety of the grid maintenance personnel. In the present power system scenario, some issues are not solved yet. One of the important issues is related to islanding fault detection in the system.

❖ PV Grid-Tied System

A PV grid-connected system uses a solar panel to generate electric energy from sunlight. power generated by the PV system is directly going to the utility grid and simultaneously when the load requires power those power requirements are fully filled by the utility grid. It's like a two-way communication system.

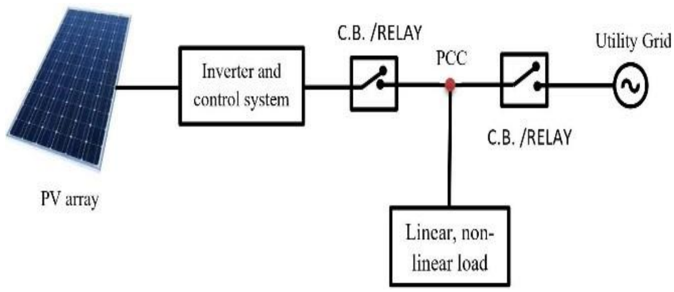

Figure 1: -Block dig. of PV grid connected system

❖ Islanding Condition

Islanding is the faulty condition in which the DG's (PV system) continue power supply to the grid even though the external grid supply is no longer present.

It can be badly affected the efficiency of the inverter, reliability, and quality of the power supply. Generally, islanding can be divided into two types one is intentional islanding and another is unintentional islanding. Unintentional islanding is more dangerous for the system this islanding has occurred without any prior knowledge. The grid disconnection in unintentional islanding occurs in the following conditions [12];

- A fault that is detected by the protection devices of the grid but not by the protection devices installed in the grid-tied DG's
- Equipment/device failure causing accidental disconnection of the utility grid
- Human error or malpractices
- act of nature

❖ Various standards for islanding

Some most reputed international organizations such as IEEE, IEC, DIN VDE, UL & Korean have defined certain standards for interconnection, operation, and control of grid-connected systems [17]. All standards are mentioned in table no. 1 [25,26,12,30].

Islanding detection methods (IDM's)

Islanding is one of the dangerous faults that occurred in the grid-tied system as mentioned above.

PARAMETERS	***STANDARDS***					
	IEEE 1547 2003	***IEEE 929-2000***	***Korean Std.***	***DIN VDE 0126-1-1***	***UL 1741***	***IEC 62116***
Maximum Voltage	110%	110%	110%	110%	110%	115%
minimum Voltage	88%	88%	88%	88%	88%	85%
Maximum Frequency	F_0+0.5 Hz	F_0+0.5 Hz	F_0+0.5 Hz	F_0+1.5 Hz	F_0+0.5 Hz	F_0+1.5 Hz
Minimum Frequency	F_0-0.5 Hz	F_0-0.5 Hz	F_0-0.5 Hz	F_0-1.5 Hz	F_0-0.5 Hz	F0-1.5 Hz
Quality Factor	1	2.5	1	2	2.5	1
Max. time for ID	2 Sec	2 Sec	0.5 Sec	0.2 Sec	2 Sec	2 Sec

Table 1: -Various standard for grid connected system

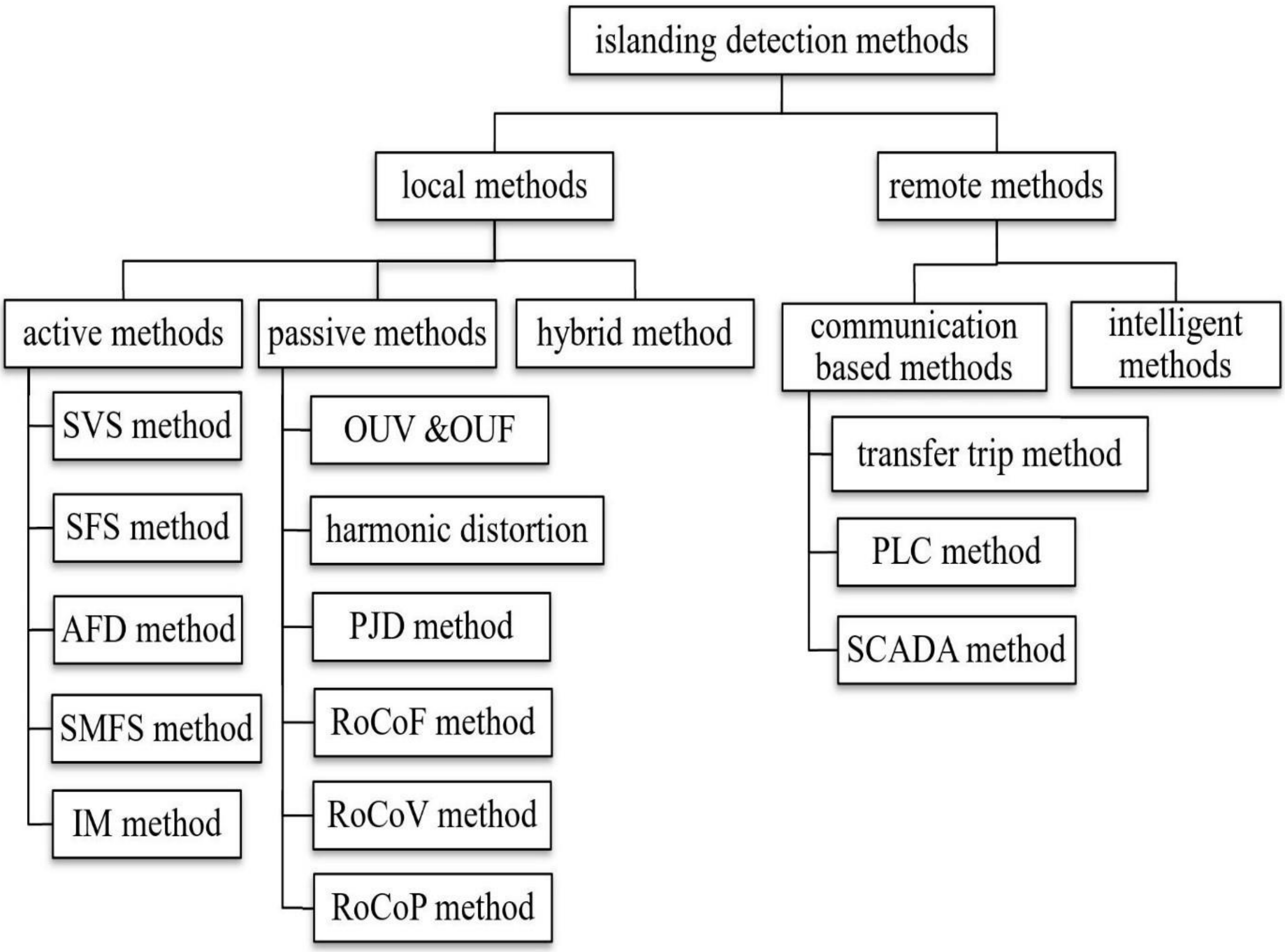

Figure 2: -Classification of islanding detection methods

Islanding is one of the dangerous faults that occurred in the grid-tied system as mentioned above. To detect this type of fault in system islanding detection methods are used. Basically, IDMs are classified into main two types as remote and local. Local methods are old methods respective to remote methods. These methods are further classified into sub-methods as shown in flow chart fig.2. all these methods are studied and analyzed in this paper thoroughly.

- **Local Methods**

A. Passive Methods

Passive islanding detection methods are one of the types of local IDM's. this is the first method that is implemented for islanding detection. These methods are invented around 1990. The basic principle of this method is to measure the parameters at PCC. A threshold value is set for these parameters. If the measured value exceeds the threshold limit, then islanding is detected in the system by this method. Passive islanding detection methods have subtypes as per the following.

A.1 Phase Jump Detection (PJD)

In this method the phase difference between the inverter terminal voltage & the inverter output current to detect islanding [1]. Under the normal condition, the phase-locked loop (PLL) is implemented due to this the voltage & current are synchronized with each other. The phase jump would not be detected till the output voltage & current are always in phase. During the islanding condition, a displacement in the phase can be found due to the shift of the voltage vector [2,3]. The equation of the phase jump algorithm & load phase angle is as in [4,5].

$$tan^{-1}\left(\frac{\frac{\Delta Q}{P}}{1+\frac{\Delta P}{P}}\right) \leq \emptyset_{threshold}$$

A.2 Harmonic Detection Method

The harmonic detection technique is based on monitoring or measuring the total harmonic distortion of the PCC voltage to detect islanding faults in the system [6]. Under the normal condition, the grid voltage & the PCC voltage will almost match each other causing negligible harmonic distortion. During islanding conditions, due to transfer of harmonics generated by inverter current to the load in the presence of non-linearities in the transformer i.e., magnetic hysteresis may increase the harmonic distortion of the output voltage. The islanding condition can be decided by the threshold value of harmonic distortion in output voltage [7,8].

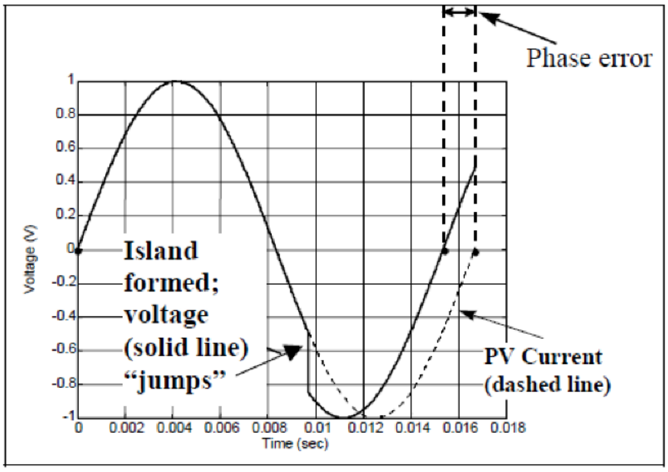

Figure 3: -Phase jump detection method

A.3 Over/Under Voltage (OUV) & Over/Under Frequency (OUF)

OUV &OUF is this method used for IDM also to protect the equipment of customers. It's a very simple method. The conventional relay is connected to a distribution feeder to identify faulty conditions during various operational modes of a grid-connected system [9]. The threshold value set for voltage & frequency in the relay, in normal conditions, the value of voltage and frequency doesn't exceed the threshold value. When the voltage & frequency value crosses the set limits the DGs are disconnected from the main utility network [10]. Usually, the voltage & frequency values depend on active and reactive power. The method measures the changes in ΔP & ΔQ at PCC according to [11]. The equation of ΔP & ΔQ is as in [12,27].

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

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

$$V' = \sqrt{P_{DG}/P_{load}} \times V$$

$$Q' = Q_{DG} = \left[\left(\frac{1}{\omega'} \times L\right) - \omega' \times C\right] \times V$$

A.4 Rate of Change of Frequency (RoCoF)

This technique uses the equation,

$$RoCoF = \frac{df}{dt} = \frac{\Delta P}{2H} f$$

In normal conditions, a change in frequency or DG output power cannot be observed. But in islanded conditions, the change is observed in frequency or output power. When the grid is disconnected from PCC a sudden power imbalance occurs and changes in the frequency at PCC can be observed over a few cycles. It will be compared with the set threshold limit [20]. If the change in frequency exceeds the predefined threshold value islanding is detected & C.B. disconnects DG from the grid [21]. Tripping time for frequency in the RoCoF method is up to six cycles & it varies from system to system.

A.5 Rate of Change of Voltage (RoCoV)

This technique calculates the rate of change of voltage at PCC from the equation,

$$RoCoV = \frac{dv}{dt}$$

When the islanding occurs the reactive power imbalance causes transient changes & voltage fluctuation at PCC this fluctuation can be detected and analyzed by this method. When the fluctuation value exceeds the threshold limit C.B. trip the DG from PCC. The detection time for this method is up to 0.125 sec. [22].

A.6 Rate of Change of Power (RoCoP)

This technique similar to RoCoV & RoCoF technique. When the grid is disconnected, there is large change occurs in load due to this change in power output of DG occurs. This method monitors change in power output and analyze those variations over a specific time period. Mathematically it is expressed as in [23].

$$RoCoP = \frac{dp}{dt} = \sum_{n=-tx}^{0} (P_{DG})_n$$

Islanding is detected when the change in power value exceeds the threshold limit. This method is fast & not affected by small power mismatch at PCC [24].

B. Active Methods

Active IDMs are introduced in 1997 to overcome the disadvantages of passive IDM's. The basic principle of these methods is disturbance signal inject at PCC for the specific parameter. In normal conditions, due to these disturbance signals, the parameters are negligibly disturbed but, when the islanding condition occurs the parameters are disturbed above a specific threshold limit. These methods have low NDZ.

The subtypes of these methods are given below,

B.1 Sandia Voltage Shift (SVS)

To detect the islanding condition in the SVS method positive feedback is applied to the output terminal of the PCC [13]. At a normal condition, there is no effect in power reduction. However, when the grid is a disconnected reduction in voltage occurs at PCC. This reduction shows the islanding condition occurs in the grid-connected system. The protection relay detects the reduction of voltage at PCC & sends a tripping signal to C.B. to cease the operation of the system [14]. The disadvantage of this method is the decrease in inverter efficiency & power quality [15].

B.2 Active Frequency Drift (AFD)

In this method, a negligible disturbance in the current signal is added to the inverter reference output current at PCC concerning the main grid voltage. In normal conditions, this disturbance does not affect any of the inverter output frequency and voltage. But, in faulty islanded conditions, this distortion affects the inverter output voltage and frequency, and hence, this change in frequency is conveyed to the commercial relay and forces to disconnect DG. Therefore, in AFD a zero-conduction time is added into each half cycle of the waveform [5] as shown in fig. 4.

$$C_f = \frac{2t_z}{T}$$

Where T is the utility voltage period & t_z is the zero time the ratio of $2t_z$ & T is called "chopping fraction or chopping frequency." This chopping fraction is low in normal conditions & high in islanded conditions. Islanding occurs when C_f crosses the threshold limit [12].

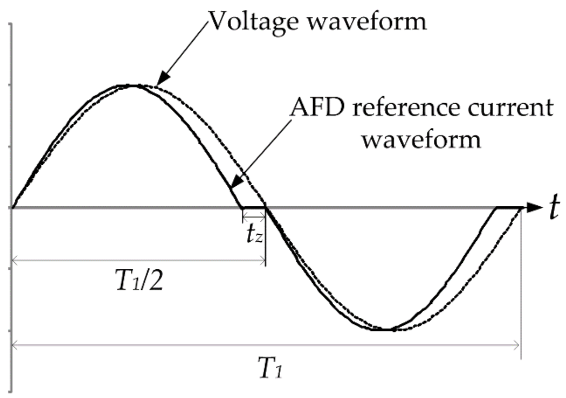

Figure 4: -AFD method waveform

B.3 Sandia Frequency Shift (SFS)

This is a new updated version of AFD with positive feedback to the frequency at PCC [18]. In normal conditions, small changes in frequency have no hazardous effect. But when the grid has disconnected the change in frequency introduces a change in frequency error which increases the frequency of the inverter. This process continues up to the threshold limit is reached and islanding condition is detected in the system. The inverter phase angle and SFS parameter are expressed as in [17].

$$\varphi_{inv} = \pi \times C_f$$

$$C_f = \left(C_{f_0} + K(f - f_n)\right)$$

This is the most efficient technique in active IDM's but it reduces the power quality of inverter & noise and harmonics can be added due to positive feedback [19].

B.4 Slip Mode Frequency Shift (SMFS, SMS)

In this technique, positive feedback is injected into the system to disturb inverter output for islanding detection [28]. The change in phase angle of DG output current is always relatively similar to the grid output voltage in normal conditions. But when the grid is disconnected the frequency of grid voltage deviates from the normal value. The deviation of frequency shows islanding condition occurs in the system. Compare to other active IDM's this technique has a small NDZ and is highly efficient in the prevention of islanding [5,29].

B.5 Impedance Measurement (IM)

The impedance measurement method depends on the variation in the high-frequency impedance of the derived data from voltage & current parameters [33]. It's somehow similar to the passive islanding detection method which measures system impedance disturbances caused by islanding. When the islanding condition occurs the value of impedance exceeds the threshold limit this indicates the islanding condition occurred in the system [35]. In some literature and scientific research found that this method has negligible NDZ especially in single inverter cases. But in multiple inverters would be forced to another for injecting a slightly different signal into the line that's why it becomes a difficult task to set a threshold value for multiple inverter systems [5,34].

C. Hybrid Methods

This method is introduced around 2003. To fulfill all the requirements of grid-connected DG systems in islanding conditions with a mixture of active and passive methods [12]. Passive & Active methods have their advantages and disadvantages. The hybrid method used advantages of both the methods and reduce disadvantages of these methods. Active methods are applied only when the passive method detect or gets problem in the detection of islanding [36,37]. It reduces errors in the detection of islanding and increases the reliability and efficiency of devices of the system. Some of the hybrid techniques are,

- ***Positive Feedback (PF) & Voltage Unbalance (VU)***
  It measures voltage unbalance in 3 phase output voltage and positive feedback is related with active IDM to eliminate the shortcoming faults of the voltage unbalance method [38,39].

  $$VUB = V_{+sq}/V_{-sq}$$

- ***Voltage & Reactive Power Shift***
  This technique measure voltage variation for a particular time period & the Adaptive Reactive Power Shift algorithm (ARPS) is used to detect islanding [40].

- ***Hybrid SFS & Q-f***
  This technique used the Active SFS method technique first & then use the Q-f droop curve. The Q-f droop curve is used to detect islanding [41].

  $$K = max\left\{\frac{2}{\pi}\left[\frac{Q_f\left(\frac{f_o}{f^2}-\frac{f}{f_o}\right)}{1+Q_f^2\left(\frac{f_o}{f}-\frac{f}{f_o}\right)^2}\right]\right\}$$

- ***Voltage & Real Power Shift***
  This technique used real power shift (active IDM) & average rate of voltage change (passive IDM) to identify islanding conditions. The RSP technique is used only when the voltage change method is unable to detect islanding [42].

Many more combinations of techniques are used to detect islanding conditions in hybrid methods. In the future hybrid of passive and intelligent IDMs can be possible for more efficient system operation.

➢ **Remote Methods**

a) Communication-Based Methods

This is one of the types of remote methods. The basic principle for this method is communication between the utility grid & the DG unit. The islanding is detected through the status of the utility grid circuit breaker and forward this information to DG unit sets to trip the circuit. These methods work with negligible NDZ, negligible effect on power quality, fast time response, and higher reliability. However, the high cost, high complexity, and complex operation are the main disadvantages of this technique. All communication-based methods are discussed below.

a.1 Transfer Trip Method

Transfer trip method used as a supplementary control method of the DG system with the utility grid [16]. The basic principle of this method is to monitor and obtain the status of the relay & circuit breakers that are capable to island the system. When the utility grid is disconnected from load or PCC due to faulty islanding conditions, the islanded areas are identified by the central algorithm. After detection of islanding, signals are sent to this islanded area to disconnect the DGs from PCC. Generally, the transfer trip method is used with the SCADA system to provide more efficient coordination between microgrid & utility grid. This method has negligible NDZ but exhibits high cost & communication failure risk [17].

a.2 Power Line Communication Method (PLC)

The power line communication technology is a remote islanding detection technique. The basic principle of this method for detecting islanding fault uses communication between the power line & DG unit. Transmission devices send a low-voltage signal continuously from the power line to the receiver devices installed at DG units. Signal design in this manner up to only 4 consecutive cycles. In normal conditions the signal is received in 4 consecutive cycles but when the islanding condition occurs the disturbance is introduced in the signal & it will disappear up to 2 or 3 consecutive cycles [31].

This method is only used for large-scale power networks because this method is costly and complex [17].

a.3 Supervisory Control and Data Acquisition Method (SCADA)

SCADA is one of the advanced IDM techniques. It is a monitoring system it continuously monitors the breakers, switching devices, & control circuits. It also monitors the system parameters like voltage, current, frequency, & power to detect any loss in the system. In the normal condition, all parameters are below the threshold value but when the islanding condition occurs the parameters are disturbed from their normal values & the SCADA system detects it and the relay sends a signal to breakers to disconnect DG from the system [32,17].

b) Intelligent Methods

Intelligent methods are similar to other remote methods but they are not required threshold values. Various AI techniques, data mining, classifier techniques are used in this method. The basic principle of these systems is analyzing all the sample data provided by the system and its filter & classifying it with an intelligent algorithm to form a strong decision-making system. With the help of data analysis and algorithms, islanding conditions are identified in the system by this method. These methods have zero or negligible NDZ. But these methods are costly and very much complex in structure. Generally, intelligent IDMs associated with signal processing methods include the following techniques [17],

- ***Artificial Neural Network based method (ANN)***
  ANN algorithm extracts important points or data from measuring data from PCC. Which are used for detection in parametric changes that occur due to islanding in the system. ANN can be described as a computational mathematical model using the biological brain of the neural network [43].

- ***Decision Tree based method (DT)***
  DT is another intelligent classifier technique used for islanding detection. It's a combination of WPT or DWT. In this method, the voltage and current signals are measured at the inverter terminal and fed to WPT or DWT for feature extraction. An extracted feature was introduced in the DT classifier for islanding detection. According to research, this method has 98% accuracy [44].

- ***Probabilistic Neural Network based method (PNN)***
  PNN is a classifier technique that can study the non-linear decision boundaries depending on Bayesian Classifier. PNN classifiers divide into 4 parts of operation input, pattern, summation, and output. This part performs its function & classifies data to identify the islanding condition [45].

- ***Support Vector Machine based method (SVM)***
  This is the most powerful technique of classification used for signal and system analysis by building decision boundaries to divide data needed for training. This technique works with autoregression modeling which extracts the important feature data from the measured PCC parameters. SVM IDM is considered impractical because it's a very complex method [46].

- ***Fuzzy Logic based method (FL)***
  FL technique uses fuzzy logic classifier for islanding detection. This technique is used with other algorithms and classifiers to provide better results. But it's a very sensitive method [47].

These are a few intelligent methods discussed above that have many advantages but they are very costly and highly complex.

❖ Comparison of various IDMs

After an encyclopedic review & comprehensive analysis, a comparison of various islanding detection methods considering their quality, advantages, disadvantages & other different parameters are shown in table 2. [1-47]

The performance capability of any islanding detection method mainly depends on the parameters given in the table. For trustworthy comparison, the advantages, limitations of the implementation process of various IDMs must be known, referring to most scientific, reliable & well-known studies. While comparing islanding detection methods, some important parameters are considered, which include NDZ, speed of operation, cost & crucks of methods with accuracy & reliability of the system.

NDZ is the most important parameter for islanding detection if a large NDZ is present in the method then the method is not reliable and it's dangerous for the system. The accuracy of the system is between 70 to 100% for best results. If this parameter goes below this range, it should be hazardous and non-reliable for the system. The cost of equipment used for methods or the cost of implementation of the method in the form of an algorithm is also an important point for IDMs. If the cost goes higher then the method becomes uneconomical. Finally, the side-effects or disadvantages of the methods according to their basic principle, accuracy, method of implementation are discussed in this review paper in detail.

According to literature research, the active method provides a fast-islanding detection method & a small non-detection zone, but in a small power system effect on power quality may degrade the performance of the power system. Its economical method, because the cost of operation & installation is low as compared to other method & complexity, is also low. The passive methods are simple economical easy to implement, but for large power systems or when the DG power & load power are balanced. This method fails to detect islanding hence, it is influenced by large NDZ, complexity is negligible in this method. Remote methods have higher efficiency, reliability, high islanding detection speed, ability to work with different system configurations. But, the cost of implementation, complexity, calculation burden are very high in these methods. It badly affects when the communication failure problem occurs in the system.

The intelligent methods use various classifiers to classify system data for decision-making system formation. Due to the very complex process, this method has high complexity, large computation burden, but it has negligible NDZ, reliable power supply with fast detection speed.

CONCLUSIONS

This paper presents an analytical and comparative study of various IDMs. A detailed classification of IDMs with their qualities and disadvantages based on important capability parameters is provided by this review. Several methods are compared with their important parameter like NDZ, speed of islanding detection, complexity, reliability, computation burden, cost of implementation, etc. all these comparisons tally with standard islanding detection regulation & IEEE standards.

The review demonstrates that the active methods have a low cost of implementation, simple, more accurate than the passive method, small NDZ, provide reliable and efficient power supply, low complexity, etc. Moreover, the other local methods have some disadvantages that can be covered by active methods. In recent times some new features & methods are also introduced in the active method. However, the remote methods have also a very accurate islanding detection, high efficiency & reliability with negligible NDZ. But, the cost of implementation is very high and it's not economically good and also a very complex computation is required for this method which sometimes fails due to communication or any other faults. Thus, the active IDMs can be considered as the best suitable option for PV grid-tied systems in recent times.

APPENDIX

- **PV** – Photovoltaic.
- **NDZ** – non-detection zone.
- **IDM** – islanding detection method.
- **DG** – distributed generator.
- **IEEE 1547(2003)** – a standard developed for DER interconnection.
- **DER** – distributed energy resources.
- **IEEE 929-2000** – IEEE recommended practice for utility interface of the PV system.
- **DIN VDE 0126-1-1** – standard for automatic disconnection device between a generator and the public low-voltage grid - Germany.
- **UL 1741** – anti-islanding & product safety standard.
- **IEC 62116** – islanding detection standard to evaluate IP effectiveness of PV inverter.
- **PCC** – point of common coupling.
- **PLL** – phase-lock loop.
- **C.B.** – circuit breaker.
- $\mathbf{C_f}$ – chopping frequency/fraction.
- **AI** – artificial intelligence.
- **WPT** – wavelet packet transform.
- **DWT** – discrete wavelet transform.
- $\mathbf{P_{load}}$ – load active power.
- $\mathbf{Q_{load}}$ – load reactive power.
- $\mathbf{P_{DG}}$ – DG active power.
- **f** – main grid frequency.
- **ΔP** – active power mismatch.
- **ΔQ** – reactive power mismatch.
- **V** – rated voltage.
- **L** – load inductance.
- **C** – load capacitance.
- **ω'** – PCC angular frequency after islanding.
- **V'** – PCC voltage after islanding.
- **H** – moment of inertia of DG.
- **N** – sampling instant.
- $\mathbf{T_x}$ – sampling window length.
- $\mathbf{\Phi_{inv}}$ – inverter phase angle.
- $\mathbf{Q_f}$ – load quality factor.
- $\mathbf{f_o}$ – frequency error.
- **t** – time.
- **K** – controller gain.
- **dv/dt** – change in voltage w.r.t. time.
- **dp/dt** – change in power w.r.t. time.
- **df/dt** – change in frequency w.r.t. time.
- $\mathbf{t_z}$ – zero time.
- **VUB** – voltage unbalance.
- $\mathbf{V_{+sq.}}$ – positive sequence voltage.
- $\mathbf{V_{-sq.}}$ – negative sequence voltage.

FIGURE 5: -Comparative analysis of various types of islanding detection method

Features	***Islanding Detection Methods***				
	Local Methods			***Remote Methods***	
	Active Methods	***Passive Methods***	***Hybrid Methods***	***Communication-Based Methods***	***Intelligent Methods***
Operation Principle	Disturbance signal added at system parameter	PCC parameter measuring	Combination of active and passive techniques	With communication, equipment communicates with grid and DG's system	Small specific impedance installed
NDZ	Small	Large	Medium	Very small	Very small
Response Time	Short	Slightly longer than active methods	Longer than the active method	Fast	Fast
Multiple Inverter Connection	Yes	No	Yes	No	No
Installation Cost	Medium	Low	High	Very high	Extreme high
Effect On Power Quality	Small degradation	No degradation	Small degradation	No degradation	No degradation
Detection Failure	Yes, possible only at higher quality factor	Yes, due to a small power mismatch to the threshold value	Yes, smaller than the active and passive method	Yes, due to communication failure	Yes, possible in a few specific conditions
Effect On Distribution System	Yes	Yes	Yes	No	No
Effectiveness	Effective	Depending on load, less effective in small load	Depending on the technique used, less effective with the passive technique	Effective	Very effective
Operation with multiple DG	Not possible	Possible	Possible	Possible	Possible
complexity	low	Very low	Medium	High	Very high
Merits	Accurate & easy to implement	Very simple & easy to implement	Accurate & simple	Accurate, efficient & fast	Reliable, accurate & fast
Demerits	Impact of complex control loop modifications & switching transients	Poor reliability	Switching transient & complex control	Complex, sensitive, expensive & mostly used for large-scale power systems	Complex, sensitive, expensive & mostly used for large-scale power systems

REFERENCES

1. Singam B., Hui L. Y., "Assessing SMS and PJD schemes of anti-islanding with varying quality factor", In power and energy conference, **(2006)**. PECon'06. IEEE international (pp. 196–201).
2. Hung G. K., Chang C. C., Chen C. L. **(2003)**, "Automatic phase-shift method for islanding detection of grid-connected photovoltaic inverters." IEEE Transactions on energy conversion, 18(1), 169–173.
3. Ropp M. E., Begovic M., Rohatgi A., Kern G. A., Bonn R. H., Gonzalez S. **(2000)**, "Determining the relative effectiveness of islanding detection methods using phase criteria and non-detection zones." IEEE transactions on energy conversion, 15(3), 290–296.
4. Ahmad K. N. E. K., Selvaraj J., Rahim N. A. **(2013)**, "A review of the islanding detection methods in grid-connected PV inverters." Renewable Sustainable Energy Rev, 21, 756–766.
5. Ahmed G. Abokhalil, Ahmed Bilal Awan, Abdel-Rahman Al-Qawasmi, "Comparative study of passive and active islanding detection methods for PV grid-connected system" sustainability **(2018)**, 10, 1798; doi:10.3390/su10061798.
6. Merino J., Mendoza-Araya P., Venkataramanan G., Baysal M. **(2015)**. "Islanding detection in microgrids using harmonic signatures." IEEE Transactions on Power Delivery, 30(5), 2102–2109.
7. Kim I. S. **(2012)**. "Islanding detection technique using grid-harmonic parameters in the photovoltaic system." Energy Procedia, 14, 137–141.
8. Velasco D. "Review of anti-islanding techniques in distributed generator." Renewable Sustainable Energy Rev. **(2010)**, 14, 1608–1614.
9. Li. C., Cao. C., Cao. Y., Kuang. Y., Zeng. L., Fang, B. "A review of islanding detection methods for microgrid." Renewable Sustainable Energy Rev. **(2014)**, 35, 211–220.
10. Mango F.D., Liserre M., Dell Aquila A., Pigazo A. "Overview of Anti-Islanding Algorithms for PV Systems. Part I: Passive Methods." In Proceedings of the **(2006)** 12th International Power Electronics and Motion Control Conference, Portoroz, Slovenia, 30 August–1 September 2006; pp. 1878–1883.
11. Shahmohammadi A., Ameli M. T. **(2014)**, "Proper sizing and placement of distributed power generation aids the intentional islanding process." Electrical Power System Res, 106, 73–85.
12. Soham Dutta, Pradip Kumar Sadhu, M. Jaya Bharata Reddy, Dusmanta Kumar Mohanta, "Shifting of research trends in islanding detection method - a comprehensive survey" springer open journal, Dutta et al. Protection and Control of Modern Power Systems **(2018)** 3:1.
13. Velasco D., Trujillo C. L., Garcerá G., Figueres E. "Review of anti-islanding techniques in distributed generators." Renew. Sustain. Energy Rev. **(2010)**, 14, 1608–1614.
14. Bahrani B., Karimi H., Iravani R., "Nondetection Zone Assessment of an Active Islanding Detection Method and its Experimental Evaluation." IEEE Trans. Power Deliv. **(2011)**, 26, 517–525.
15. Merino Fernández J., Mendoza-Araya P., Venkataramanan G., Baysal M., "Islanding detection in microgrids using harmonic signature." IEEE Trans. Power Deliv. **(2015)**, 30, 2102–2109.
16. Raza S., Mokhlis H., Arof H., Laghari J.A., Wang L., "Application of signal processing techniques for islanding detection of distributed generation in distribution network: A review." Energy Convers. Manag. **(2015)**, 96, 613–624.
17. Min-Sung Kim, Raza Haider, Gyu-Jung Cho, Chul-Hwan Kim, Chung-Yuen Won, Jong-seo Chai, "Comprehensive Review of Islanding Detection Methods for Distributed Generation Systems." Energies **(2019)**, 12, 837.
18. Zeineldin H. H., Conti S. **(2011)**, "Sandia frequency shift parameter selection for multi-inverter systems to eliminate non-detection zone." IET Renewable Power Generation, 5(2), 175–183.
19. Wang X., Freitas W., Xu W., Dinavahi V. **(2007)**, "Impact of DG interface controls on the Sandia frequency shift anti islanding method." IEEE Transactions on Energy Conversion, 22(3), 792–794.
20. Yu B., Matsui M., Yu G. **(2010)**, "A review of current anti-islanding methods for photovoltaic power system." Solar Energy, 84(5), 745-754.
21. Freitas W., Xu W., Affonso C.M., Huang Z., "Comparative analysis between ROCOF and vector surge relays for distributed generation applications." IEEE Trans. Power Deliv. **(2005)**, 20, 1315–1324.
22. Merlin V. L., Santos R. C., Grilo A. P., Vieira J. C. M., Coury D. V., Oleskovicz M., "A new artificial network-based method for islanding detection of distributed generators." International Journal Electrical Power Energy System **(2016)**, 75, 139–151.
23. Zhang Y., Sun H., Lopes L. A. **(2007)**, "an islanding detection enhancer for a system with multiple photovoltaic inverters."
24. Jahdi S., Lai L. L., "DG islanding operation detection methods in combination of harmonics protection schemes." In Proceedings of the 2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies, Manchester, UK, 5–7 December **(2011)**; pp. 1–8.
25. IEEE Recommended Practice for Utility Interface of PV systems, **(IEEE Standard 929-2000)**.
26. IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, **(IEEE Standard 1547-2003)**.
27. Ammu susan sabu, sindhura rose thomas, Lakshmi K. R., anju James, "passive anti-islanding protection for grid connected solar photovoltaic power plant: A case study." IJERT **(2015)**, volume 4, issue 04.
28. Akhlaghi S., Akhlaghi A., Ghadimi A. A., "Performance analysis of the Slip mode frequency shift islanding

detection method under different inverter interface control strategies." In Proceedings of the **(2016)** IEEE Power and Energy Conference at Illinois (PECI), Urbana, IL, USA, 19–20 February 2016; pp. 1–7.

29. Emadi A., Afrakhte H., Sadeh J., "Fast active islanding detection method based on second harmonic drifting for inverter-based distributed generation." IET Gener. Transm. Distrib. **(2016)**, 10, 3470–3480.
30. Basso T. S., & DeBlasio R. **(2004)**., IEEE 1547 series of standards: Interconnection issues. IEEE Trans Power Electron, 19(5), 1159–1162.
31. Wang W., Kliber J., Zhang G., Xu W., Howell B., Palladino T., "A Power Line Signaling Based Scheme for Anti-Islanding Protection of Distributed Generators—Part II: Field Test Results." IEEE Trans. Power Deliv. **(2007)**, 22, 1767–1772.
32. Bayrak G., Kabalci E., "Implementation of a new remote islanding detection method for wind-solar hybrid power plants." Renew. Sustain. Energy Rev. **(2016)**, 58, 1–15.
33. Hamzeh M., Farhangi S., Farhangi B., "A new control method in PV grid connected inverters for anti-islanding protection by impedance monitoring." In Proceedings of the 2008 11th Workshop on Control and Modeling for Power Electronics, Zurich, Switzerland, 17–20 August **(2008)**, pp. 1–5.
34. Ku Ahmad K. N. E., Selvaraj J., Rahim N. A., "A review of the islanding detection methods in grid-connected PV inverters." Renew. Sustain. Energy Rev. **(2013)**, 21, 756–766.
35. Kotsopoulos A., Duarte J., Hendrix M., Heskes P., "Islanding behavior of grid-connected PV inverters operating under different control schemes." In Proceedings of the Power Electronics Specialist Conference (PESC'02), Cairns, Australia, 23–27 June **(2002)**; pp. 1506–1511.
36. Cossent R., Gómez T., Frías, P. **(2009)**., "Towards a future with large penetration of distributed generation: Is the current regulation of electricity distribution ready." Regulatory recommendations under a European perspective Energy Policy, 37(3), 1145–1155.
37. Perlenfein S., Ropp M., Neely J., Gonzalez S., Rashkin L. **(2015)**., "Subharmonic power line carrier (PLC) based island detection." In applied power electronics conference and exposition (APEC), 2015 IEEE (pp. 2230–2236). Piscataway: IEEE.
38. Menon V., Nehrir M. H. **(2007)**., "A hybrid islanding detection technique using voltage unbalance and frequency set point." IEEE Trans Power Syst, 22(1), 442–448.
39. Mahat P., Chen Z., Bak-Jensen B. **(2008)**., "Review of islanding detection methods for distributed generation." In electric utility deregulation and restructuring and power technologies, 2008. Third international conference on (pp. 2743–2748). Piscataway: IEEE.
40. Yin J., Chang L., Diduch C. **(2006)**., "A new hybrid anti-islanding algorithm in grid connected three-phase inverter system." In 2006 IEEE power electronics specialists conference (pp. 1–7).
41. Vahedi H., Noroozian R., Jalilvand A., Gharehpetian, G. B. **(2010)**., "Hybrid SFS and Qf islanding detection method for inverter-based DG." In power and energy (PECon), 2010 IEEE international conference on (pp. 672–676). Piscataway: IEEE.
42. Mahat P., Chen Z., Bak-Jensen B. **(2009)**., "A hybrid islanding detection technique using average rate of voltage change and real power shift." IEEE Transactions on Power Delivery, 24(2), 764–771.
43. Hartmann N. B., dos Santos R. C., Grilo A. P., Vieira J. C. M., "Hardware Implementation and Real-Time Evaluation of an ANN-Based Algorithm for Anti-Islanding Protection of Distributed Generators." IEEE Trans. Ind. Electron. **(2018)**, 65, 5051–5059.
44. El-Arroudi K., Joos G., Kamwa I., McGillis D. T., "Intelligent-Based Approach to Islanding Detection in Distributed Generation." IEEE Trans. Power Deliv. **(2007)**, 22, 828–835.
45. Samantaray S. R., Babu B. C., Dash P. K., "Probabilistic Neural Network Based Islanding Detection in Distributed Generation." Electr. Power Compon. Syst. **(2011)**, 39, 191–203.
46. Matic-Cuka B., Kezunovic M., "Islanding Detection for Inverter-Based Distributed Generation Using Support Vector Machine Method." IEEE Trans. Smart Grid **(2014)**, 5, 2676–2686.
47. Hashemi F., Ghadimi N., Sobhani B., "Islanding detection for inverter-based DG coupled with using an adaptive neuro-fuzzy inference system." Int. J. Electr. Power Energy Syst. **(2013)**, 45, 443–455.

AUTHORS PROFILE

Mr. Satyajit S. Chopade received his bachelor's degree from K.D. K. college of engineering affiliated with RTMNU, Nagpur, India, in 2020 from electrical engineering. He is currently working toward his master's in technology from Priyadarshini college of engineering affiliated with RTMNU, Nagpur, India, from (industrial drives & control) electrical specialization. He has published 5 research papers in different research journals. His research interest is in non-conventional energy sources, power systems & drives.

Dr. S. P. Muley completed her Ph.D. from VNIT, Nagpur in 2013. Her research areas include drives, control and renewable energy systems. She has 20 papers in international journals to her credit. She has over 25 years of experience in industry and research.