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REVIEW

A Survey on Recent Developments of Islanding Detection Techniques

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ABSTRACT

Nowadays, the power distribution system comprises distributed generators (DGs) that provide low-cost electricity and have fewer adverse environmental consequences. In some situations, these DGs continue to supply the nearby loads owing to line outage and system separations creating islands. This causes unacceptable power quality conditions. If this is not detected, it may harm the load. This type of islanding may also occur in the transmission lines because of stability issues caused by transmission line outage. If this is not detected at an early stage, the entire system may collapse. Harmful islanding needs to be detected and addressed. This study describes several recent methods and standards related to islanding detection. The acceptable voltage and frequency range, testing conditions, and maximum islanding detection time are mentioned in the IEEE1547, UL1741, and IEEE929 standards. The detection algorithms can be active, passive, hybrid, and communication based. These algorithms have been discussed in detail in this article.

Keywords: Active method, communication-based method, distributed generation, hybrid method, islanding detection, passive method; power systems

Introduction

Artificial neural networks of variable hidden layer sizes have been tested for islanding detection in IEEE 9 bus system in [1]. The neural network works as a simple classifier for separating islanding and nonislanding cases. The same methodology has been improved in [2] using probabilistic algorithm for islanding detection. Firstly, artificial neural network incorporates the selection of parameters of the hidden Markov model, which are later used for islanding detection during data unavailability. Bilateral reactive power variation is the main logic in [3] for islanding detection. This is one of the hybrid approaches for islanding detection. Characteristic analysis has been performed to obtain design parameters of the hybrid method. The method has been validated under IEEE Std 929 and IEEE Std 1547 criterion. In [4], a model component-based islanding detection method has been tested on a prototype system. A detection factor is required for this method. It can detect islanding in exact power balance condition. A fuzzy neural-based method has been implemented in [5] for calculating probability of islanding in a system where there are multiple connections with the grid. The probability is determined using active, passive, and communication-based hybrid methods. The auxiliary service required for the probability is not received in the control center. The method proposed in [6] is a hybrid method using communication and passive methods for smooth operation and stability, which is ensured by adjusting voltage and power of the generator. This method is not affected by any change in generation and load. Voltage injection in d-axis current is an effective tool for islanding detection within 810 ms in large photovoltaic system as experimented in [7] under standard situations mentioned in IEEE 1547-2008 and UL 1741. The nondetection zone has been found negligible experimentally in [8], which is a system involving one cycle-controlled inverter that is free from phase-locked loop implementation. This method is an active method, but external signal injection is not required. An active method used in [9] can detect islanding in PMSG-based DGs (distributed generators) within 178 ms. Frequency changes implicitly during post islanding condition, whereas external signal is injected. In some adverse situations, the islanding is detected within 200 ms. A solar farm is present in the 6 bus test system used in [10]. IEC62116 criterion is applied to the measurements obtained from phasor measurement units to detect islanding as in [10]. This method is a communication-based method. The measurements and reporting standards are different in case of μPMUs, which are used in [11] and [12] for islanding detection in distribution systems. Both the methods in [11] and [12] are passive. P-type μPMU is used in [11]. The Fortescue transform helps compute phase angle sequence. The difference between positive absolute angle component and zero absolute angle components is used to initiate signal for accomplishing intelligent islanding. A

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quick and reliable method in [12] using kurtosis and random forest classifier can detect islanding in 20 ms.

El Khalil El-Arroudi et al. [13] have developed islanding detection technique based on threshold values of voltage, frequency, rate of change of frequency, and power. In [14] a ROCPAD islanding relay has been developed and islanding conditions are tested for different power mismatches. Negative sequence of voltage at point of common coupling as well as Parseval's theorem is applied for islanding detection in [15]. When the energy content of the signal exceeds a threshold value, islanding is confirmed. A new Fast Gauss-Newton Algorithm (FGNWA) has been developed in [16] for islanding detection. Gauss-Newton algorithm combined with approximated Hessian matrix generates FGNWA. A low-cost autoground system has been developed in [17]. It has a single installation point, but this method is unproven in the field and causes faults in the DGs.

Machine learning techniques such as support vector machine and ensemble tree classifier are used in [18] for islanding detection. The method in [19] can detect islanding for both inverter-based DG and synchronous DG. K-fold cross validation has been used for testing the accuracy of the algorithm. This validation produces biased results for low values of k. In [20], autoregressive coefficients of voltage and current have been used for islanding detection. The detection time is 50 ms, which is high to some extent. An islanding detection on real-time Distributed Energy Control Center microgrid has been experimented in [21]. This laboratory provides a unique facility at the Oak Ridge National Laboratory. The algorithm in [22] can detect islanding by connectivity checking. It is based on network topology and does not require data on the network parameters. The rate of change of voltage phase angle (ROCOVPA) has been incorporated in [23] for islanding detection for several case studies defined by the IEEE 1547 and UL 1741 standards. An adaptive ensemble classifier has been used in [24].

Adaptive decision mechanism is designed with this algorithm to adjust the decision time with events classification. Probability of islanding (PoI) [25] is estimated in aggregation with active, passive, and communication-based methods. If the central control for microgrid (CCMG) does not receive PoI, two supplementary process are performed to detect islanding in an alternative way. Using two methods during communication failure is not computationally efficient. Intelligent relay based on decision trees [26] has been reported to reduce nondetection zone boundaries, described by established methods. Helmholtz oscillator can detect islanding in near zero active power mismatch as testified in [27] in multiple DG based system. Modal components can be calculated from phasor data as mentioned in [28]. Islanding detection factor can be calculated from modal components. Despite the small detection time, nondetection zone has not been verified in this method.

A real-time islanding detection method on Turkish power system has been implemented in [29]. This method can heal the power system on the basis of the severity index. A novel distributed energy resource-driven nondetection zone (D2NDZ) method has been proposed in [30]. D2NDZ formulas are initially recognized by experimental study, and then parameters are determined by optimization method. An adaptive neuro-fuzzy interface system for islanding detection has been validated by UL1741 standards in [31]. Gibbs phenomenon can be incorporated with RMS and THD for islanding detection as declared in [32]. Measurements obtained from µPMU are further processed by Fortescue transform to detect islanding [33]. In this method, the detection time is high.

Artificial neural network-based islanding detection has been presented in two studies [34, 35]. These two methods are moderately time consuming. A new event-based ellipsoidal estimation set [36] has been proposed for islanding detection in a 2-kW single-phase grid-connected power generation system. Event triggering can reduce the transmission frequency for saving the communication resources. Dual frequency based active islanding detection method described in [37] is also advantageous for grid impedance detection. The proposed hybrid islanding technology in [38] involves both the mean of absolute d-axis voltage variation (ADVV mean) and mean of absolute rate of change of d-axis voltage (AROCODV mean). The event detection is represented geometrically in [39] for islanding detection. Principal component analysis is used to reduce data dimension in this method. In the literature [40], several tendencies and future of islanding detection methods are prescribed. Role of micro-phasor measurement unit during uncertainties in power system are analyzed in [41]. Phase comparison–based islanding detection index has been proposed in [42]. The chance of a cyberattack has been reduced in [43] during islanding detection. The threshold values for islanding detection have been estimated experimentally in [44]. Discrete fractional Fourier transform has been implemented in [45] for fast detection of islanding. GOOSE-based passive islanding has been tested in hardware in loop in [46]. Islanding probability can be found out experimentally during missing communications as publicized in [47].

A variety of technologies for islanding detection is illustrated in Section 2. Comparisons of different islanding detection methods are given in Section 3. Section 4 concludes the article.

Main Points

- Classification and description of islanding detection techniques.
- Discussion of several standards; for example, IEEE1547, UL1741, and IEEE929, related to islanding.
- Classifying the occurrence of islanding in different systems is important for selecting appropriate algorithms and techniques. This article presents the consequences of islanding on different systems. It also describes the consequences of solar distributed generators (DGs), wind DGs, and synchronous DGs in a distribution system islanding.
- Comparison of nondetection zone and advantages and disadvantages of various types of islanding detection algorithms.
- Conclusion and future scope of the topic based on the discussion and comparison of algorithms.

Description and Classification of Islanding Detection Techniques

In this section, the islanding has been visualized in a simple system, some important standards have been discussed before the detailed description, and comparison of islanding detection methods have been performed.

Occurrence of Islanding on Simple Systems

When the inverter is working in a grid-tied mode, its frequency is dominated by the grid frequency through a feedback controller. When island occurs, the power frequency of the inverter deviates from nominal value, and the voltage profile becomes unstable in nature. The controller is then arranged to make the inverter operative in a stable region. Some dual-mode inverters can operate in both grid-tied and off-grid condition. The changing of controller from grid-tied mode to islanded mode requires islanding detection. Islanding test setup consisting of an inverter, *RLC* load, and utility grid is shown in Figure 1. The solar panel supplies DC power to the inverter, and the inverter feeds AC supply to the local *RLC* load.

$P_L + jQ_L$ is the amount of power taken by the *RLC* load. Islanding occurs when $\Delta P + j\Delta Q$ is zero. Performance of islanding detection method can be evaluated by gradually equating $P_L + jQ_L$ and $P_{DG} + jQ_{DG}$ in a step-by-step manner. For visualizing the islanding situation in transmission system, the solar inverter setup and the controller can be replaced by generating station along with a step-up transformer as depicted in Figure 2. The mathematical interpretation is equivalent to the distribution system as mentioned before. Islanding detection time should be less if voltage and frequency deviation is more. (1) and (2) are followed for Figures 1 and 2, respectively.

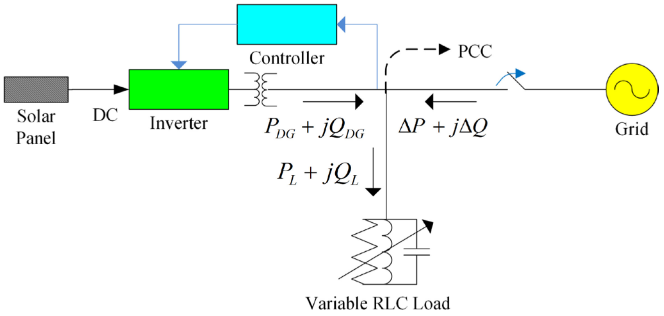

Figure 1. Schematic diagram of islanding study in a distribution system

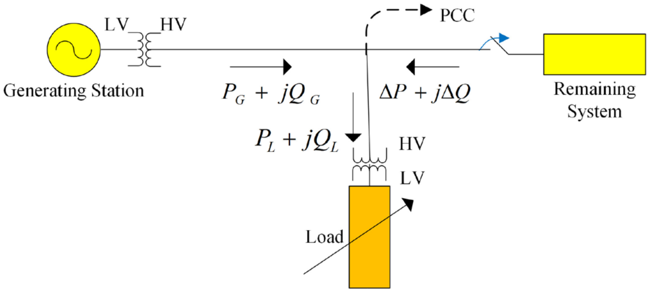

Figure 2. Schematic diagram of islanding study in a transmission system

$$(P_{DG} + jQ_{DG}) - (P_L + jQ_L) = \Delta P + j\Delta Q \tag{1}$$

$$(P_G + jQ_G) - (P_L + jQ_L) = \Delta P + j\Delta Q \tag{2}$$

Some more details can be incorporated for nondetection zone. It can be evaluated based on power mismatches. Let V_{mx}, V_{mn}, f_{mx}, f_{mn}, Q_f be maximum voltage, minimum voltage, maximum frequency, minimum frequency, and quality factor, respectively. The threshold power mismatches are obtained as (3) and (4).

$$\left(\frac{V}{V_{mx}}\right)^2 - 1 \le \frac{\Delta P}{P} \le \left(\frac{V}{V_{mn}}\right)^2 - 1 \tag{3}$$

$$Q_f\left(1-\left(\frac{f}{f_{mn}}\right)^2\right) \le \frac{\Delta Q}{P} \le Q_f\left(1-\left(\frac{f}{f_{mx}}\right)^2\right) \tag{4}$$

The values of R, L and C in Figure 1 can be so adjusted as to get zero power mismatch as mentioned below in (5), (6), (7), and (8).

$$R = \frac{V^2}{P_L} \tag{5}$$

$$L = \frac{V^2}{2\pi f Q_f P_L} \tag{6}$$

$$C = \frac{Q_f P_L}{2\pi f V^2} \tag{7}$$

$$f = \frac{1}{2\pi\sqrt{\frac{L}{C}}} \tag{8}$$

where P_L represents load power and f represents operating frequency.

Several Standards Related to Islanding Detection

There are several control strategies, standards, and islanding testing criteria. According to IEC 62116, the allowable voltage range is 0.85 to 1.15 of nominal voltage, and the frequency deviation is allowed up to ±1.5 Hz from nominal frequency. The voltage and frequency deviation for IEEE1547 and IEEE929 are the same for safe operation. The voltage range is 0.88–1.10 of nominal voltage, and frequency range is within 59.3–60.5 Hz for both of IEEE1547 and IEEE929.

It is mentioned in UL1741 standard that the load should be adjusted in such a way to make the DG supply 25%, 50%, 100%, and 125% of the rated active power. The reactive power is also adjusted by ±5% of rated active power.

Classification of Islanding Circumstances and Islanding Detection Methods

Islanding detection techniques can be broadly classified as active, passive, communication-based, and hybrid methods. The detailed classification is showed in Figure 3.

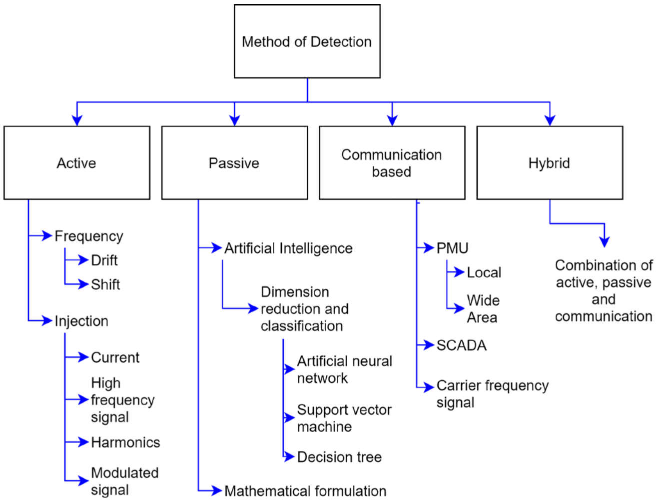

Figure 3. Classification of islanding detection techniques

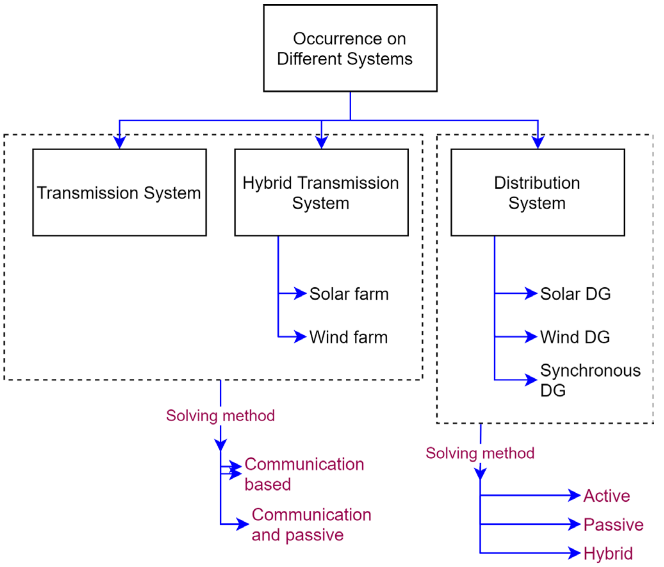

Figure 4. Classification of islanding based on occurrence of different systems

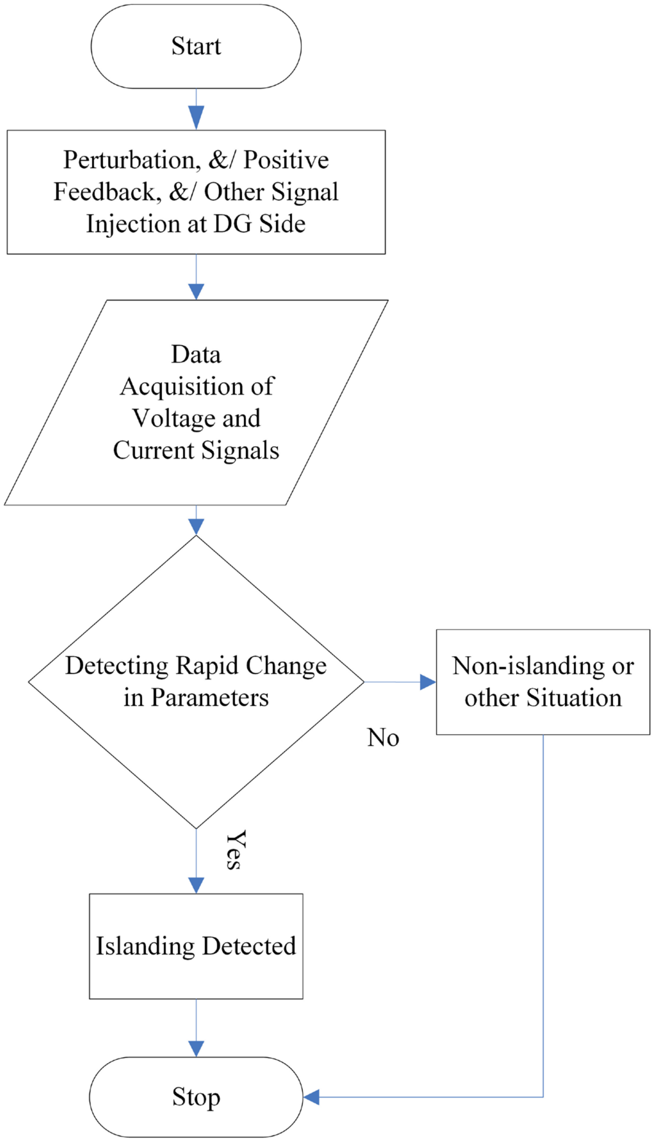

Figure 5. Active islanding detection

Islanding may occur in different systems that play an important role in choosing a detection method. The occurrence of islanding in different systems has been categorized in Figure 4

It is observed that the communication-based method is applicable to transmission related systems, and other methods are applicable to distribution systems. The descriptions of four classifications: active, passive, hybrid, and communication-based methods are discussed in this subsection.

A comprehensive active method flowchart is depicted in Figure 5.

According to Figure 5, rapid change in parameter is observed owing to signal injection in the islanding condition. Rapid change is unavoidable when DG power equals load power consumption. Therefore, the active method has no nondetection zone in zero mismatched condition. However, the nondetection may occur in some situation other than zero mismatched condition. In some advanced active methods, the nondetection zone is persuasively made zero in a hybrid mode.

The passive islanding detection is generalized in Figure 6. No external signals are injected, and only the measurements are analyzed. Nondetection zone is present to an accountable extent for passive methods. Nondetection occurs when $P_L + jQ_L$ is equal to $P_{DG} + jQ_{DG}$. However, this method does not affect the power quality.

Communication-based methods are described in Figures 7 and 8. As seen in these figures, the communication-based islanding detection is allocated into two different flowcharts. According to

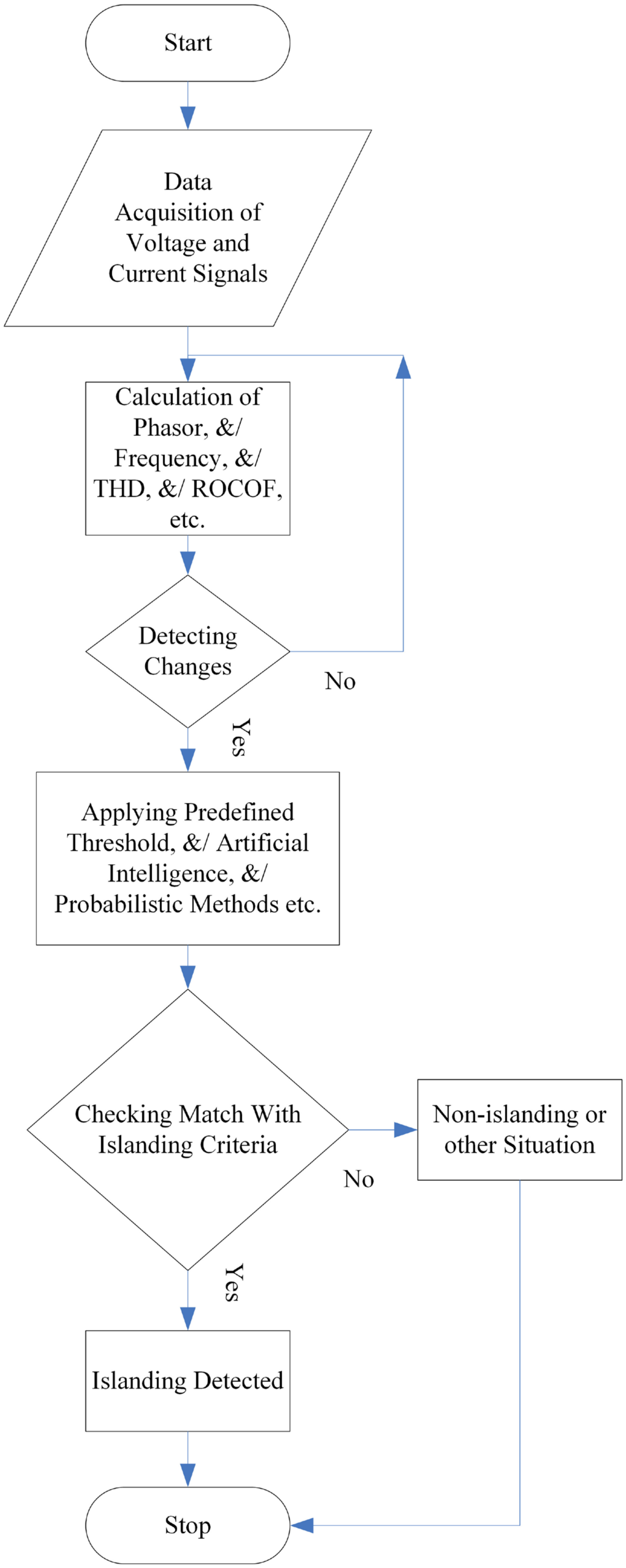

Figure 6. Passive islanding detection

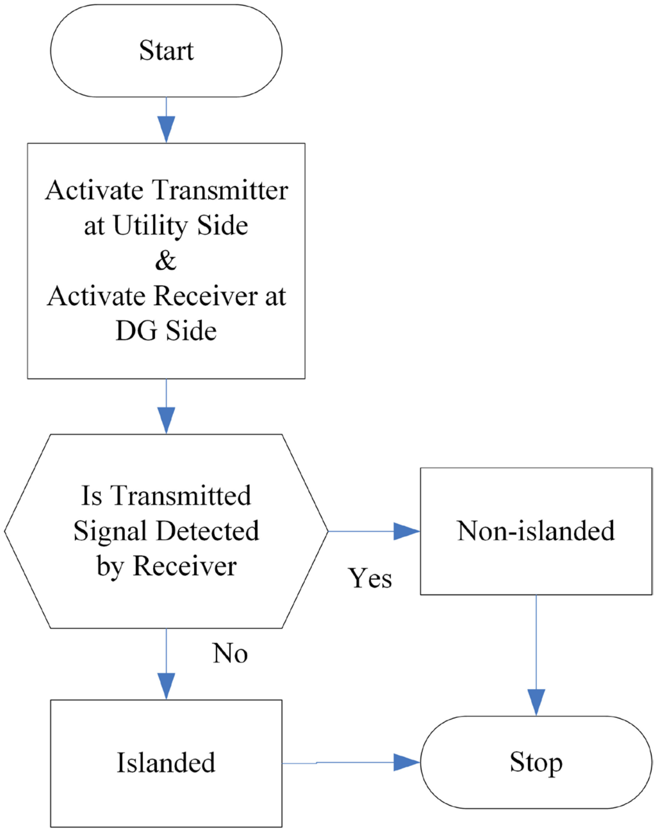

Figure 7. Radio/microwave/power line carrier/ signaling based islanding detection

Figure 7, carrier frequency signal is used to communicate between the utility and inverter sides. One transmitter is present in the utility, and several receivers are present with all the inverters. The transmitter and receiver pair helps detect the islanding condition. If the receiver does not obtain proper carrier frequency signal sent by the transmitter, islanding is confirmed. In phasor measurement (Figure 8), devices are placed in both the utility and DG sides. The difference in measurements between the two sides reflects islanding condition.

As seen in Figure 9, both passive and active criteria are applied successively. The limitations of both active and passive methods are compensated by the hybrid method in Figure 9. Nondetection zone created in the passive method is cleared by the active method, and the nondetection zone that would have been produced in active is already eliminated in the passive method.

Comparison of Different Algorithms

All the algorithms have some limitations. A nondetection zone is always present for each of the algorithms. Generally, passive methods fail in a region where load demand is equal to DG generation. If the phase angle of the load is zero, it will not create much phase shift during islanding; therefore, the use of phase-jump-method is limited to islanding detection in linear loads. Islanding detection using harmonics analysis is not effective for loads with strong low pass characteristics or having high quality

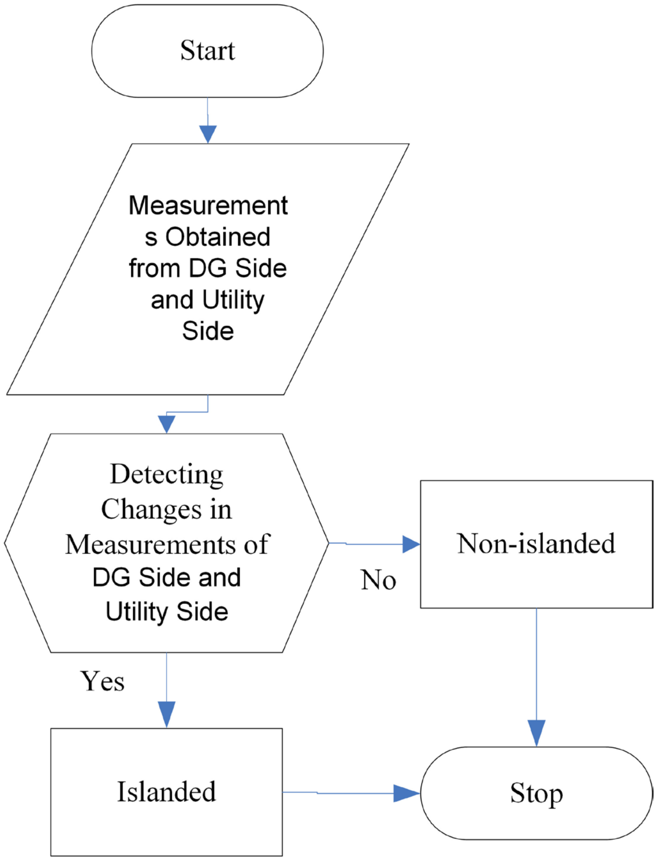

Figure 8. SCADA/synchrophasor based islanding detection

factor. For an electrically strong grid, the impedance of the generator is practically nonzero. Thus, an impedance threshold of small value is specified by the impedance measurement technique. The islanding detection criterion lies below this small threshold value. If local impedance is already less than the threshold, impedance-based islanding detection method is not applicable. For communication-based islanding detection using power line carrier communication, the load may produce a carrier signal similar to the signal produced during islanding condition. This may cause false islanding detection. Few aspects of active methods are described in Table 1.

Active frequency drift, Sandia frequency shift, and slip mode frequency shift are the earlier methods of active islanding detection. Currently, researchers are interested in more advanced methods, for example, pulsating signal injection, capacitor insertion, Q-V droop, d-axis disturbance injection, etc.

Several comparative analyses of passive methods are given by Table 2. Some threshold limits of electrical parameters shown in Table 2 were used earlier to detect islanding. However, in the present situation, the practice of several signal processing techniques, for example, wavelet transform, hyperbolic-s transform, and mathematical morphology, etc. are used to detect islanding conditions. These methods have proven useful for islanding detection accurately.

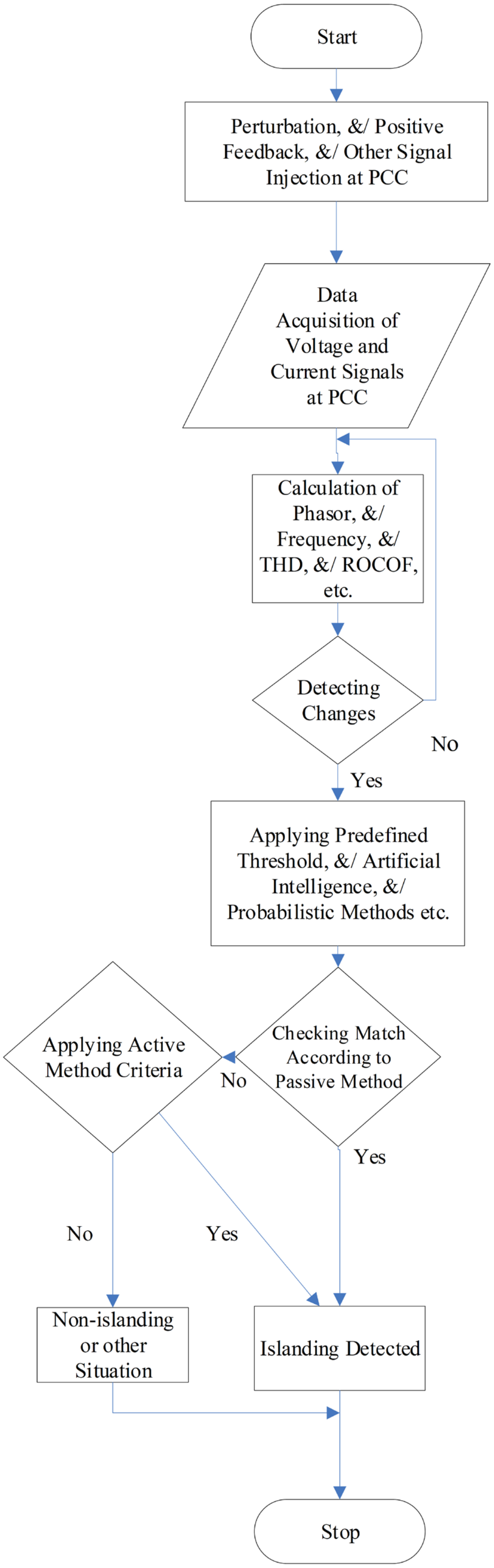

Figure 9. Hybrid islanding detection

Table 1. Comparison of active islanding detection algorithms

Algorithm	Advantage	NDZ	Disadvantage
Active frequency drift	• Easily implemented using microcontroller.	• NDZ is relatively large than other active methods. • NDZ depends on chopping fraction.	• Adverse effect on power quality. • Instability in positive feedback. • Current discontinuity may cause radio frequency interference.
Slip mode frequency shift	• Easy to implement. • Applicable to multi-inverter system.	• Small NDZ.	• Adverse effect on power quality. • Instability in positive feedback.
Sandia frequency shift	• Easy to implement • Compromise between power quality and islanding detection effectiveness.	• Small NDZ. • NDZ depends on gain value.	• Higher gain may cause transients, and lower gain causes large NDZ. • Instability in positive feedback.
Improved active frequency drift	• 30% less THD compared with AFD [36]. • Faster operation.	• Improved NDZ compared with AFD.	• More complicated than AFD • Instability if positive feedback is used.
Adaptive fuzzy Sandia frequency shift	• Gain is optimized to reduce both NDZ and transients.	• Smaller NDZ than in Sandia frequency shift.	• More complicated than Sandia frequency shift. • Instability in positive feedback.
Average absolute frequency deviation	• Detects stable islanding. • Do not involve system stability. • Power quality and power factor is improved by using small reference current.	• Small reference current may cause large NDZ.	• False islanding detection owing to frequency deviation other than islanding condition. • Rechecking must be done for islanding confirmation.
Impedance-based analysis of active frequency drift	• Can detect islanding even when power supplied by inverter is equal to power consumed by load (impedance insertion is used in this condition).	• Small NDZ	• Similar disadvantage as active frequency drift.
Real power shift	• Clear discrimination between islanding and nonislanding • Simple algorithm, easy for implementation.	• Small NDZ.	• Degrades power quality. • Less stable operation.
Negative sequence current/power injection	• Faster operation • Applicable to parallel DG and double DG system.	• NDZ can be reduced using RLC space based on a relatively minor modification in the control algorithm.	• Degrades power quality. • Less stable operation. • Instability owing to positive feedback. • Detection time doubles if the load parameters are in the NDZ space.
Capacitor insertion	• Provides reactive power support. • Prevent islanding for small duration.	• Small NDZ.	• Economically not feasible. • Difficulty in determining the part of a power system responsible of installing capacitor for a multi-DG system.
High frequency signal injection	• Islanding is detected in a few milliseconds. • Negligible adverse effect owing to injected high frequency voltage. • 0.3% line voltage is required for islanding detection causing 0.11% THD.	• Small NDZ.	• Degrades power quality. • Less stable operation. • Unstable operation.
Controlled inverter	• Improves stability and islanding detection performance. • Applicable for weak grids.	• NDZ present.	• Stability depends on the design of integral controller.
Reactive power control/voltage regulation	• Applicable to high penetration PV unit. • Small effect on power quality. • No interference in multi-PV system.	• Small NDZ depending upon proportional controller gain.	• Stability depends on the design of integral controller.

d-axis disturbance signal injection	• Minimum effect on power quality. • Reliable operation. • Wavelet fuzzy neural network used instead of PI controller.	• Quasi-zero NDZ.	• Similar disadvantage as wavelet and fuzzy logic.
Frequency fuzzy positive feedback	• Positive feedback is restricted depending upon system stability. • Decreased NDZ compared with other positive feedback method.	• Small NDZ.	• Similar disadvantage as using fuzzy logic. • Positive feedback may reduce stability.
Q-V droop plus correlation	• THD is between 0.01% and 0.38%. • Better than slip mode frequency shift, active frequency drift, and reactive power control.	• NDZ is determined by the region under frequency threshold.	• Unstable operation owing to positive feedback. • Similar disadvantage as correlation. • Islanding detection time is moderate (123.5–216.9 ms).
Transient stiffness measure	• Applicable to multi-DG system, avoids spectrum overlapping. • Detecting islanding for micro-grids with droop control. • Perturbations injected by the proposed method have no effect on the stability.	• Negligible NDZ	• None.
Pulsating high frequency signal injection	• Can handle linear and nonlinear loads. • Multi-DG operation is possible.	• Not described.	• Unstable operation and power quality issue.

Table 2. Comparison of passive islanding detection algorithms

Algorithm	**Advantage**	**NDZ**	**Disadvantage**
Kalman filter	• Able to take into account quantities that are partially or completely neglected in other techniques. • Detection within 45 ms.	• NDZ present.	• Complicated procedure. • Can only be used for linear state transition and Gaussian model.
Under/over voltage	• Simple to implement • Low-cost active method	• ND occurs when inverter power matches load consumed.	• Under/over voltage may be caused owing to nonislanding condition. • Large NDZ. • Detection time is higher. • Load having zero phase angle may not produce phase angle change in islanding condition.
Voltage vector shift			
Rate of change of voltage phase angle			
Under/over frequency			
Fifth harmonic	• Satisfies IEEE Standard 1547. • Eliminates NDZ.	• Negligible NDZ in normal condition.	• Similar fifth harmonic can be generated from noise or other nonislanding criteria.
Switching frequency from inverter	• Can detect islanding in 20ms. • Can be applied to multi-DG system.	• Zero NDZ.	• None
Wavelet	• Better than Goertzel or discrete Fourier transform based algorithm. • Fast algorithm.	• NDZ present.	• Can be improved using other algorithms.
Data mining	• Eliminate false detection. • Superior decision making.	• Medium NDZ.	• Computational effect is high during starting
Bayesian	• Faster operation • Accuracy up to 100%	• Depends upon Bayesian classifier.	• None
Duffing oscillator	• Applicable when noise to signal ratio is high. • Can detect weak signals.	• Small NDZ. • NDZ of the proposed method is subject to the frequency deviation rather than the load quality factor.	• None

Table 2. Comparison of passive islanding detection algorithms (Continue)

Algorithm	Advantage	NDZ	Disadvantage
Machine learning and wavelet design	• Wavelet parameters are determined using Procrustes analysis. • Better than simple wavelet transform. • Machine learning helps in automatic classifier.	• NDZ is smaller than in wavelet algorithm.	• None
Reference impedance based or frequency dependent impedance change	• Enhancement to the UF/OF method. • Considering harmonic frequencies other than fundamental. • Standard 1547-2003 satisfied.	• Reduced NDZ compared with UF/OF.	• None.
Phase space technique	• Stabilize the islanded part of the system with minimum load curtailment. • Better than wavelet.	• NDZ present.	• Slower procedure.
Thevenin-like model	• High sensitivity and reliability, does not require expert tuning. • Can detect islanding when DG balances loads. • Detection time is 100–200 ms.	• Null NDZ.	• Linear representation is not helpful in all cases.
Islanding search sequence	• Impact on normalized active and reactive power is less than 1%. • Optimized procedure of islanding detection within 250 ms (including the relay/contactor opening time, voltage collapse within safe limit). • Overall system perturbation is very less (1%).	• NDZ present	• None. • Islanding detection time is high (250 ms).
Hyperbolic s-transform	• Islanding detection in 22 ms, 22 ms, and 25 ms for Hyperbolic, Time to time and Mathematical method respectively. • Applicable for noisy conditions. • Sag, swell, flicker, inrush, and oscillation can be detected with good accuracy. • Applicable to multi-DG system.	• Less NDZ.	• None.
Time to time transform			
Mathematical morphology			
Dynamic estimator	• Superior performance for high quality factor. • Less than four cycles needed to determine islanding.	• Small NDZ.	• None.
Oscillation frequency	• Islanding detected in 40 ms. • Better than ROCOF method.	• NDZ less than 1.6% for rated DG power.	• Calculation of damping coefficient is omitted resulting in inaccuracy.

NDZ: nondetection zone, AFD: active frequency drift, THD: total harmonic distortion

Some important aspects of communication-based methods are discussed in Table 3. Principal component analysis becomes unavoidable to reduce the dimensionality when applying phasor measurement units. These reduced dimensional features are used for islanding detection. GPS based communication is also considered for synchrophasor technology. Synchrophasor based islanding detection is computationally lengthy and cost effective. However, these methods are reliable, modern, and fast compared with the other communication-based methods.

Future Scope

A lot of new studies can be conducted on the basis of current literature on islanding detection techniques as mentioned below:

- Based on the severity of the islanding, a ranking can be proposed for a particular system. The ranking can help the controller to take priority-based actions.
- All transmission islandings are not hazardous, and it is important to classify hazardous and nonhazardous islanding.

Table 3. Comparison of communication-based islanding detection algorithms

Algorithm	Advantage	NDZ	Disadvantage
Radio or microwave	• No power quality issue.	• Normal operating state has no NDZ.	• Affected by other radio frequency or microwave signals. • Expensive.
Power line signaling	• Can be used for data as well as sending power.	• Small NDZ.	• High carrier frequency involved for data communications and the sub-optimal design of power systems is required when transporting high frequency signals.
Power line carrier	• Does not affect power quality. • Does not involve transient condition. • Co-operate to increase ride through capability.	• NDZ does not exist in normal condition.	• Very expensive and uncommon.
Fiberoptic	• Operated in long range. • Low loss of signal. • Large data carrying capacity. • No electromagnetic radiation.	• No NDZ present.	• The transmitter and receiver for fiberoptics are very expensive. • Cannot carry electrical signal, thus backup required for control action.
Leased line	• Not affected by external noise. • No power quality issue. • Less expensive. • Reliable operation.	• No NDZ present.	• Delay is considerable for slow connection.
Transfer trip scheme	• No power quality issue.	• NDZ is present because of weak in-feed condition.	• Islanding detection speed depends on circuit breaker and re-closer operating time. • Weak in-feed condition has adverse effect. • Loss of communication is considerable.
SCADA	• Eliminates islanding condition. • Takes control over islanding situation.	• No NDZ present.	• Not synchronized. • Costly procedure.
Phasor measurement unit	• Fast, accurate, modern, and synchronized technique. • Can be applied to wide area islanding detection. • Loss of communication is rare.	• No NDZ present.	• Expensive • Principal component analysis becomes mandatory to reduce dimensionality.

NDZ: nondetection zone

Nonhazardous islandings are really necessary in certain situations to maintain stability in the islands.

- Universal controller, which can operate in both grid-tie and off-grid modes, has been developed in some studies. The controller does not require any islanding detection technique for the operation. Future research can be conducted related to the universal controller for improvement of smart microgrid expertise.
- Probabilistic approaches are highly appreciable for manipulation of islanding scenarios in some adverse situations, for example, cyberattack, lost communication, missing data, etc.

Conclusion

We have discussed a total of 18 active islanding detection techniques. All the methods are applied to distribution systems only. The nondetection zone is negligible. The power quality issue is unavoidable in active islanding detection as mentioned in the literature. Notably, 22 kinds of passive methods have been elaborated. These methods are applied to both transmission and distribution systems. No power quality issue has been reported in the literature for passive methods. These methods are faster than the active methods, but nondetection zone where islanding cannot be detected is more. Eight types of communication-based method have been discussed in this article. These methods are applicable to large transmission and distribution systems for accurate islanding detection. Communication-based methods are costlier than passive methods.

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