# Inverter On-board Detection Methods to Prevent Unintended Islanding

*Industry Practices*

**3002014728**

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Technical Update, December 2018

EPRI Project Manager

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# ABSTRACT

To address the long-standing concern for unintended islanding with distributed energy resources (DER), a multiyear research project is underway. It is aimed to address the growth in deployment, expanded capabilities and new performance options in inverter-connected DER. Key outcomes of the project are expected to be definition of generic islanding detection methods, effectiveness evaluation in typical feeder environments and new criteria for screening interconnection requests. This project builds on the recent Sandia National Laboratories work, "Unintended Islanding Detection Performance with Mixed DER Types, SAND2018-8431", July 2018. [1] Additional work in underway is to look at how prevention is affected by different island detection methods, ride-through performance categories and feeder details. Several more EPRI and Sandia reports are planned to deliver results of this research.

This report provides a literature review of the state-of-the-art Island Detection Methods (IDMs). It is intended to be comprehensive as to available technologies for use in inverter-based DER. There are four main types of on-board detection, including passive, active, hybrid, and computational-intelligence-based. The operating principle, characteristics, strength and weakness of each IDM are analyzed in detail. To add relevance for the descriptions, and the wide range of on-board detection options, a survey of DER manufacturers was conducted. The results showing methods commonly used and other key factors are provided. Also discussed in this report are remote communication methods that are often utility-controlled islanding preventions, such as direct transfer trip.

**Keywords**

Unintentional islanding
Distributed energy resources (DER)
DER interconnection
Inverter onboard islanding detection
Run-on Time (ROT)

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[1] Sandia report, "Unintentional Islanding Detection Performance with Mixed DER Types," July 2018. Available online: https://energy.sandia.gov/energy/renewable-energy/solar-energy/photovoltaics/publications/.

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## Product Title: Inverter On-board Detection Methods to Prevent Unintended Islanding: Industry Practices

**PRIMARY AUDIENCE:** Utility technical staff, planners and research community involved with distributed energy resources (DER) interconnection criteria, technical reviews or protection requirements. Results are particularly applicable in areas with expected high penetration of inverter-connected DER systems (PV or storage) on distribution circuits.

**SECONDARY AUDIENCE:** Stakeholders responsible for distributed energy resources (DER), planning activities, project design, interconnection reviews, and system impact studies. This included consultants and plant developers, inverter manufacturers and other stakeholders in the business of DER.

### KEY RESEARCH QUESTION

This update report addresses the question, what islanding detection methods (IDMs) are in current practice? The following broader set of questions are addressed in the overall research.

- Which inverter on-board IDMs are more effective for unintended island detection?
- Are the inverter on-board IDMs still effective when multiple DGs, generators, and/or motor loads are present and operating?
- What are the impacts of grid-support functions on islanding prevention?
- Which conditions have high risk of islanding and what are the critical parameters?
- How can the existing island protection screening procedures be adapted to comply with the new IEEE 1547 standard and stay effective in high-risk conditions?
- How can we mitigate the risk of unintended islands at minimum cost?

### RESEARCH OVERVIEW

State-of-the-art islanding detection methods (IDMs), including both inverter on-board techniques and utility-controlled islanding preventions, were reviewed and summarized. The operating principle, characteristics, strength and weakness of each IDM are analyzed in detail. Based on general knowledge of available methods, a survey was developed and sent to 27 major DER manufacturers to gather and analyze information surrounding existing real-world anti-islanding protection techniques. This report is intended to convey current industrial practices to mitigate islanding risk, including adoption of different IDMs. Also considered are anticipated adaptions to comply with the new IEEE 1547 standard.

### KEY FINDINGS

- Islanding detection methods are mainly implemented in PV and ES inverters, but they are also available in fuel-cell, wind-turbine and future EV to grid inverters.
- Many detection methods can be indemnified in the literature, however currently passive and active are the main techniques adopted in commercial DER inverter.
- Survey respondents indicated confidence that their inverters detect islands at any conditions within 2s, and 80% of respondents claimed that islands can be detected within 1s.

- A few respondents indicated they do intend to change islanding detection with the advent of grid support.
- Communication based anti-islanding techniques are regarded as the most promising anti-islanding protection in future.

**WHY THIS MATTERS**

By compiling technical information and lessons-learned from inverter testing, EPRI is facilitating knowledge sharing among utilities and DER manufacturers. This helps to build core knowledge and leverage insights for the anti-islanding prevention during DER integration. Results inform and help to avoid common mistakes on future projects; and provides an up-to-date reference point on detection strategies, insights, notable activities, and screening procedures.

**HOW TO APPLY RESULTS**

Results suggest that DER manufacturers need to consider effectiveness of on-board islanding detection under different expected conditions and not just certification test conditions. With expected higher penetration levels, all previous methods should be reviewed as early as possible in the inverter design stages. For utilities contemplating islanding protection requirements for high DER penetration applications, use this material as a reference and to guide questions about inverter IDMs. Confirm that less effective methods are not used in high penetration or problematic case. Share lessons-learned regarding islanding related protection such as submittal requirements, screening review, protection studies and commissioning practices.

**LEARNING AND ENGAGEMENT OPPORTUNITIES**

- This ongoing project promotes industry collaboration including workshops with participants, sharing of DER interconnection practices and definition of generic requirements expected simplify specification and approvals.
- The results are of wide interest not only for utilities but also other stakeholders in grid connected. EPRI research programs directly involved in this work are Integration of Distributed Generation (P174) and Distribution Protection (P200C).

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**PROGRAM:** Integration of Distributed Energy Resources (P174)

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# 1 INTRODUCTION

Concern for unintended islanding of distributed energy resources (DER) has been an important consideration for interconnection since third-party generation was allowed by PURPA in 1978. When the distributed generation capacity on a feeder is close to the minimum load, common utility practice is to require preventive measures such as direct transfer trip (DTT). These practices evolved with engine-driven synchronous generators. Today, they are being applied to the growing penetration of inverters widely used in solar and energy storage applications.

Compared to rotating machines, grid-connected inverters have a much wider-range of performance options. For example, the inverter's capabilities to provide grid support have been recognized and are now required for equipment certification. Ride-through and voltage support capabilities of smart inverters, while good for grid support, directly increase concerns for unintended islanding. Stand alone and microgrid operating capabilities also add to islanding concerns.

Advances in both grid and DER technologies suggest that there may be better ways to operate with DER in the future.

## 1.1 Background/Objectives

The concern for unintended islanding is of increasing relevance with today's higher numbers and greater grid support capabilities in inverter-connected DER. Traditional requirements to prevent islanding such as DTT have become more common, while in many cases, more contentious. One of the motivations for this research is to determine if there is a better way to address the long-standing issue of unintended islanding protection. The direction is to look at opportunities related to advances in inverter technology.

With increasing penetration of DERs such as solar photovoltaic (PV) and energy (ES), it is possible that local generation can match or exceed the local load. The potential for unintended DER operation after a feeder (or section) opens is a significant protection and safely concern. Consequently, all inverter-based DER have been required (since IEEE 1547-2003) to have on-board island detection systems to prevent operating without the grid. Large synchronous machines nearly always require a means to transfer trip if the feeder breaker opens. These protections must be coordination with utility-controlled operations such as circuit reconfiguration to restore service.

Practices have been evolving unevenly as larger numbers of inverter based DER are deploying in different jurisdictions. When penetration level exceeds limits established by distribution utility or the state commissions additional protection is required. Utility-controlled direct transfer trip (DTT) is the most common. The schemes usually disconnect selected DG if an upstream breaker is open. These technologies can detect unintended islanding immediately and alleviate the need for on-board island detection.

Decisions on what prevention is required in specific cases depends on penetration levels related to either peak or minimum load. Typical penetration limits allowed are 15%, up to 30%, of peak load, and when DER equipment is certified to pass the industry anti-islanding test. In some cases, inverter connected DER have been allowed up to 100% of minimum load, if certified for onboard anti-islanding protection. Mixed DER with solar inverter and gas engine generators will normally require utility-controlled feeder-level protection against islanding. Adding inverter grid support and ride through bring most of these rules of thumb into question.

Direct communication can be relatively expensive and is only practical for individual large DER plants. Consequently, for highly distributed DER such as solar PV, on-board detection is the primary and often the only protection option. While inverter grid support capabilities are highly recognized and defined in performance requirements, details around the inverter's island detection methods are generally not well defined or recognized.

The idea promoted in this research is that detection method is an important factor in the risk of unintended islanding. Also, the technologies available for island detection have evolved just as grid support functions have evolved. These detection methods need to be better understood and considered as a factor in interconnection. If on-board detection can be shown to be secure and highly reliable then additional preventions may not be required.

## 1.2 Scope of Research

A better understanding of onboard detection methods is the main objective of this collaborative research project. Further definition and evaluation of inverter capabilities are important as DER take on grid support capabilities and functions. The work recognizes that long-standing concerns of unintentional islanding are further elevated with inverter ride-through and var-support requirements.

This project considers that utilities responsible for connection as well as DER owners may have options previously not considered to meet interconnection requirements. Well-defined islanding protections improve safety of line workers and the public, reduces exposure of utility equipment, as well as, controls not designed for islanded operation, and lowers the risk of damaging DER by out-of-phase reclosing. If islanding detection can be better understood, then alternative preventions measures, and related costs, may be avoided.

Figure 1-1 illustrates the four main tasks and promised deliverables included in this project. In the first task, the non-proprietary response models of the major DER on-board islanding detection methods (IDMs) will be developed, and their effectiveness will be evaluated in multiple testing platforms, as well as under various penetration levels and grid characteristics.

Based on testing and analysis results, key factors in the risk of unintentional islanding conditions will be identified and utilized to update anti-islanding screening procedures, such as NY Joint Utilities, CA IOUs and Sandia's screening procedure[2], considering the new IEEE 1547. The ultimate objective is to help utilities mitigate the risk of unintended islanding at minimum cost, considering inverters' on-board detection capabilities as well as feeder and load characteristics of a specific site.

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[2] Guidelines Document for Determining When Additional Anti-Islanding Studies are Necessary (SAND2012-1365)

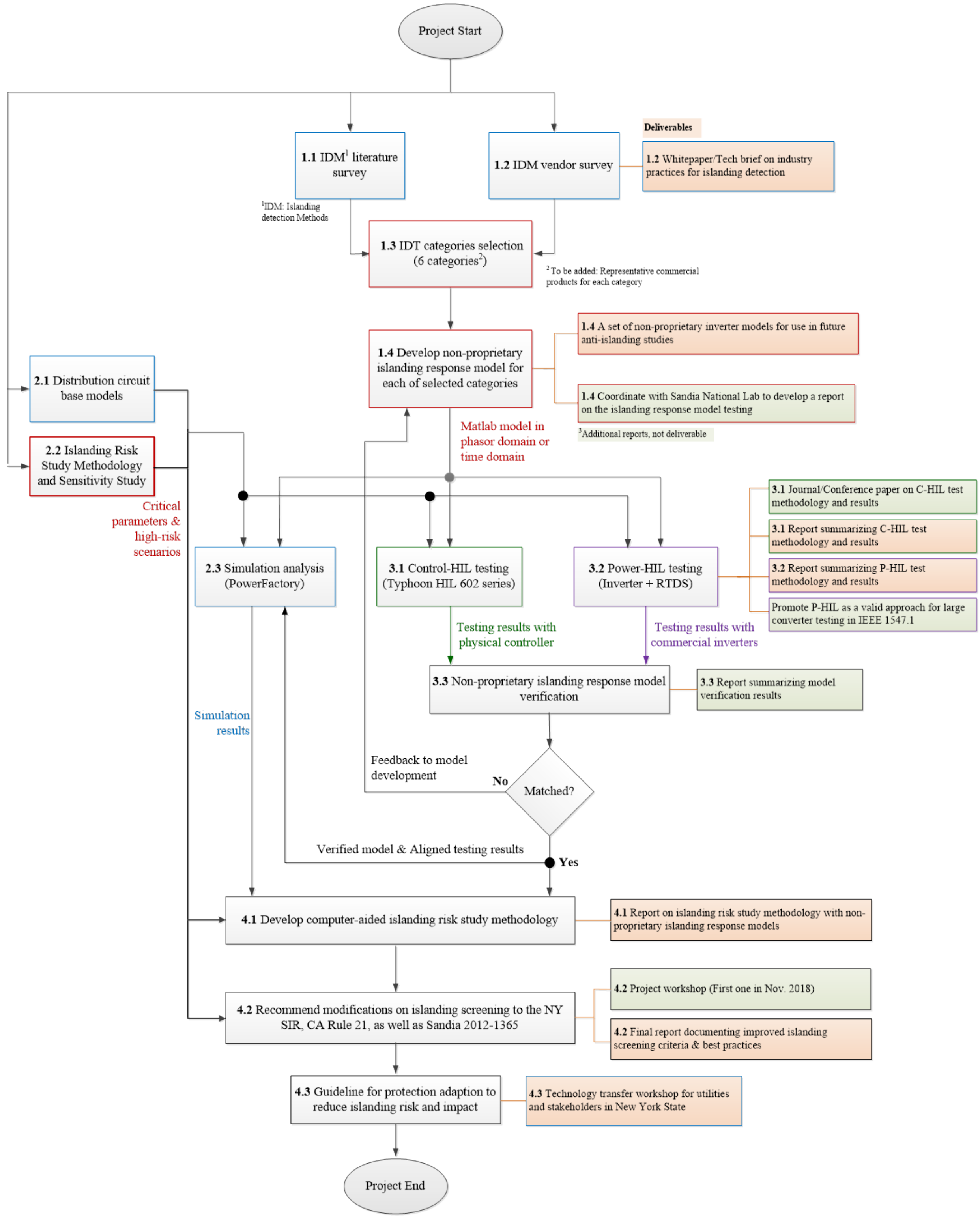


**Figure 1-1**
**Project task flow.**

## 1.3 Covered in this Report

This research update report, as the first of several, addresses common inverter industry practices to detect island conditions. In section 2, the report provides the literature review of the state-of-the-art in industry detection methods. Five different groups are identified including passive, active, hybrid, intelligence-based techniques, and remote methods. Also, their apparent advantages and disadvantages are compared. Section 3 reviews the results of an inverter manufacturer survey. Conclusions as well as description of future work are given in section 4.

The key findings from the vendor survey are summarized below:

1. Islanding detection methods are mainly implemented in PV and ES inverters, but they are also available in fuel-cell, wind-turbine and future EV to grid inverters.
2. Many detection methods can be indemnified in the literature, however currently passive and active are the main techniques adopted in commercial DER inverter.
3. Survey respondents indicated confidence that their inverters detect islands at any conditions within 2s, and around 80% of respondents claimed that islands can be detected within 1s.
4. A few respondents indicated they do intend to change islanding detection with the advent of grid support.
5. Communication based anti-islanding techniques are regarded as the most promising anti-islanding protection in future.

# 2

# REVIEW ON STATE-OF-THE-ART ISLANDING DETECTION METHODS

Currently, there are two prevailing approaches for anti-islanding protection.

The primary approach relies on anti-islanding protection implemented in DER inverters. The inverter on-board islanding detection methods (IDMs) generally rely on certain abnormalities in local voltage or frequency and are much less expensive than utility-controlled approaches. Due to the limited local information, these on-board IDMs are more suitable for smaller DER systems, and their effectiveness may degrade in multi-inverter scenarios. According to the different detection mechanisms, the on-board IDMs can be categorized into four groups: passive, active, hybrid, and computational intelligence based techniques.

Besides, the implementation of DTT and other communication based techniques can be relatively complex because of the point-to-point communication requires separate transmitter for each DG installation. It is even more complex if feeder reconfiguration is needed to accommodate load change or restore service after a grid outage.

Figure 2-1 defines the classification of the prevalent IDMs, including 11 passive methods, 13 active methods, 7 hybrid methods, 5 computational intelligence-based methods, and 7 feeder level methods. Other schemes exist, but they are either not widely used, or derived from the listed ones, and thus not included in this report.

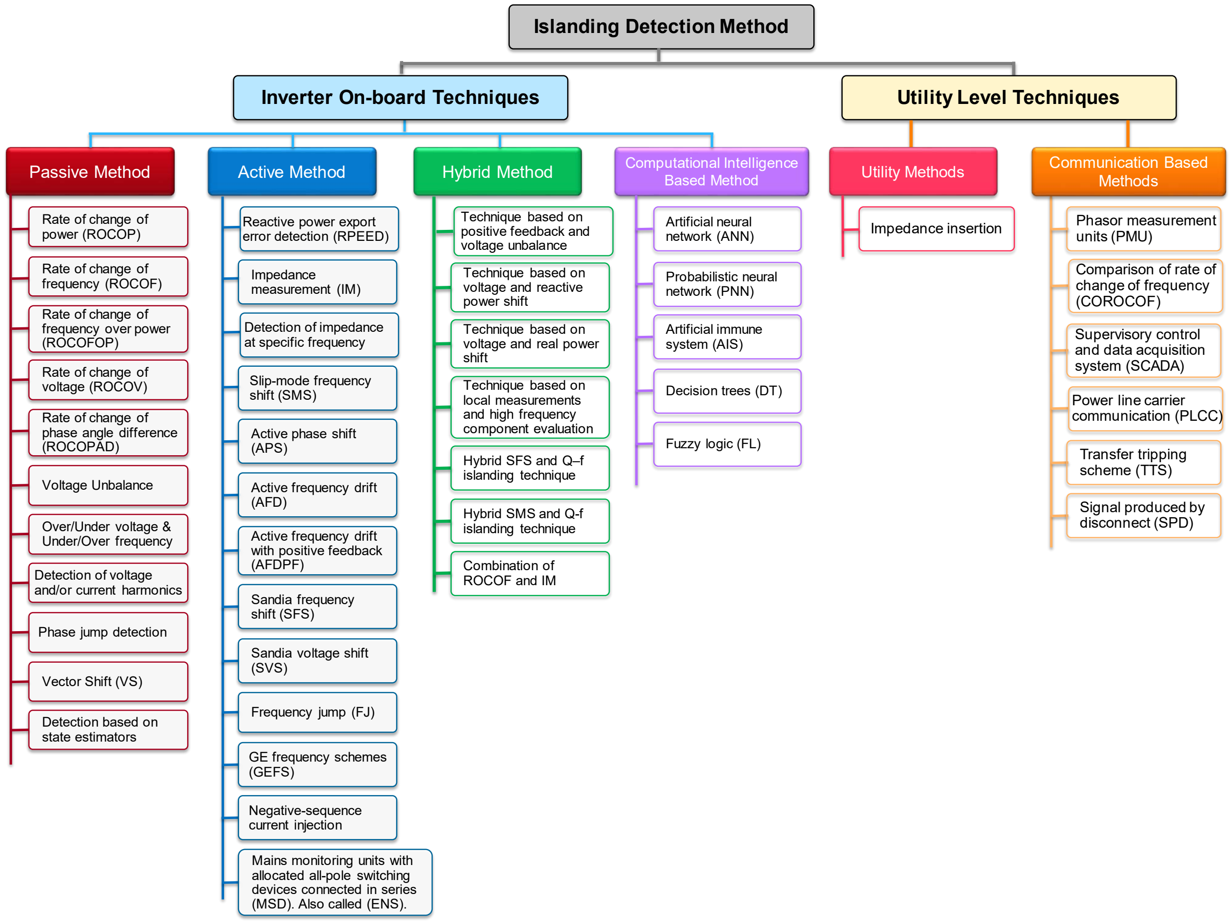


**Figure 2-1**
**Classification of islanding detection methods**

## 2.1 Passive Techniques

The most commonly used passive IDMs are summarized below, which directly monitor the parameters at the point of common coupling, including voltage, current, frequency, harmonics and phase angle. [3,4] The state of the system is then determined and islanding can be detected by comparing these parameters to the preset thresholds. No perturbation injection is involved. Table 2-1 compares the key metrics of each passive IDM.

*Rate of change of Power (ROCOP)* – Monitor the rate of change of power ($\mathrm{d}p/\mathrm{d}t$), which will be greater during the islanding operation. DG will trip when ROCOP exceeds the pre-selected trip setting value.

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[3] C. Li, etal, "A review of islanding detection methods for microgrid," *Renewable and Sustainable Energy Reviews*, vol. 35, 2014, pp. 211 – 220.

[4] F. De. Mango, M. Liserre, A. Dell'Aquila, A. Pigazo, "Overview of anti-islanding algorithms for pv systems, part 1: passive methods", *12th International Power electronics and Motion Control Conference*, 2006, pp. 1878-1883.

*Rate of change of frequency (ROCOF)* - Monitor the rate of change of frequency (d*f*/d*t*), which will be greater during the islanding operation. It can be executed by a ROCOF relays in the system. Any fluctuation over a pre-selected period of time will trigger the ROCOF relay and disconnect the DG.

*Rate of change of frequency over power (ROCOFOP)* – Monitor the rate of change of frequency over power (df/dp), which will be greater in a small DG system. For an island with small mismatch between power generation of DG and load, rate of change of frequency over power provides higher sensitivity than rate of change of frequency over time.

*Rate of change of voltage (ROCOV)* – Monitor the rate of change of voltage (d*v*/d*t*), which will be greater during the islanding operation. DG will trip when ROCOV exceeds the pre-selected trip setting value.

*Rate of change of phase angle difference (ROCOPAD)* – Monitor the rate of change of phase angle difference between voltage and current at the DG side. DG will trip when *ROCOPAD* exceeds the threshold.

*Voltage Unbalance* – Monitor the voltage unbalance factor, defined as the ratio of negative sequence voltage over positive sequence voltage. DG will trip when UV exceeds the threshold.

*Under/Over voltage & Under/Over frequency* – During islanded operation, the voltage and frequency will deviate when power between DG generation and loads is not matched. When $\Delta$P and $\Delta$Q are sufficiently large, the voltage and frequency will eventually go beyond the normal operating ranges and trip the DG through UOF/UOV protection.

*Detection of voltage and/or current harmonics* – Monitor the total harmonic distortion (THD) of DG side voltage and/or current, and trip the DG when THD exceeds the threshold. Two main reasons for harmonic increase during islanding operation are 1) distorted voltage caused by the non-linear behavior of transformer magnetic core, 2) current harmonics introduced by DER inverters.

*Phase jump detection* – Monitor the DG terminal voltage and current to detect a sudden angle difference change or "jump", as illustrated in Figure 2-2. Trip the DG if the phase shift is higher than the pre-selected threshold.

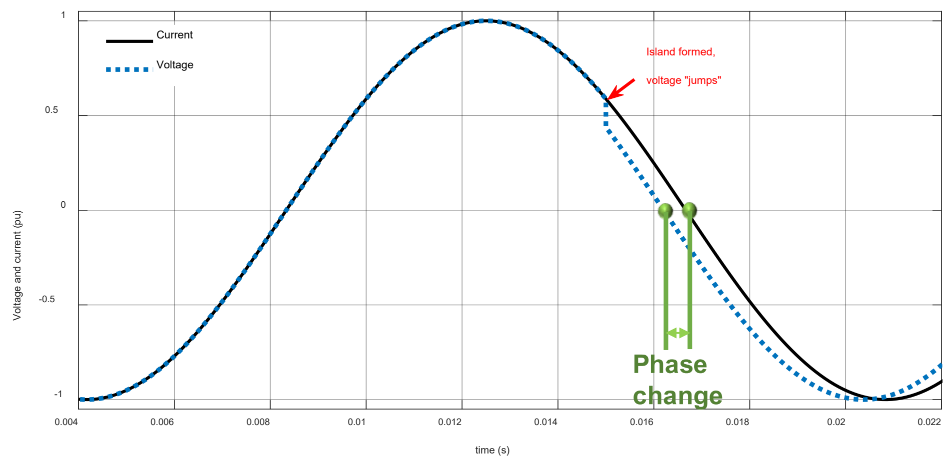


**Figure 2-2**
**Phase jump islanding detection.**

Vector Shift (VS) – After island forms, the generator will feed larger (or smaller) loads and decelerate (accelerate). Meanwhile, DG terminal voltage (VT) changes with increased (decreased) current. Consequently, the difference between generator internal voltage and VT become larger (smaller) and the voltage phasor change its direction.

*Detection based on state estimators* – Estimate the system states using a voltage sensor-less control, and trip the DG when energy mismatch exceeds the threshold.

The passive IDMs normally feature low cost, fast detection speed and low or no impact on power quality. However, it is difficult for them to detect islanding when the generation and loads are closely matched in the islanded system, leading to a relatively large non-detection zone (NDZ). Besides, special considerations are needed for the threshold selection. Lower threshold may cause nuisance tripping, while relatively high threshold could reduce the detection effectiveness and lead to larger NDZ. These limitations, however, could be overcome by adopting intelligent classifiers and/or advanced signal processing techniques, or combing with active IDMs.

## 2.2 Active Techniques

The basic operating principle of popular active IDMs are summarized below.[5,6,7] These methods intentionally create and introduce perturbations into the system parameters, such as voltage, frequency and harmonics. These perturbations are designed to have negligible impact during grid connected operation while significantly disturb the potential stable operation of DGs in the islanded grid. Table 2-2 compares the key metrics of each active IDM.

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[5] M. Karimi, etal, “Photovoltaic penetration issues and impacts in distribution network – A review,” *Renewable and Sustainable Energy Reviews*, vol. 53, 2016, pp. 594 – 605.

[6] W. Bower, M. Ropp, “Evaluation of islanding detection methods for utility-interactive inverters in photovoltaic systems,” SAND2002-3591, Nov. 2002.

[7] F. DeMango, M. Liserre, A. Dell’Aquila, “Overview of anti-islanding algorithms for pv systems, part 2: active methods”, *12th International Power electronics and Motion Control Conference*, 2006, pp. 1884-1889.

*Reactive power export error detection (RPEED)* – Detect the reactive power generated by DG at PCC (located between DG and grid) or the location of RPEED relay, and trip the DG if the reactive power flow exceeds its preset threshold. During grid connection, the reactive power can be maintained, while it may exceed the limit when the grid is disconnected.

*Impedance measurement (IM)* – Monitor the change of system impedance ($d_{VPCC}/d_{Iinv}$), and trip the DG when it exceeds the preset threshold. Generally, the value of impedance greatly increases when system becomes islanded.[8]

*Detection of impedance at specific frequency or harmonic injection* – This method intentionally injects specific current harmonics, and monitor the PCC voltage at the harmonic frequency. Trip DG if the voltage harmonic exceeds its preset threshold. Due to the relatively low impedance of the grid at harmonic frequency, the harmonic current mainly flows into the grid during grid connection. After disconnecting from the grid, the harmonic current flows into the load and produces a higher harmonic voltage at PCC, which will be monitored to trip the DG during islanding. [9]

*Active frequency drift (AFD)* – As illustrated in Figure 2-3, this method intentionally varies the frequency of the DG output current injected into the PCC, through positive feedback. It lightly distorts the current waveform, through a wave chopping, to change the frequency.[10] During grid connection, the system frequency is clamped by grid and stay stable. During grid disconnection, the distorted current waveform produces a phase error between voltage and current. In order to eliminate this error, DG drifts its current frequency and further increases the phase error. This positive feedback process iterates until trip the DG due to under/over frequency (UOF) protection.

The chopping fraction is

$$cf = \frac{2t_z}{T_v} \quad \textbf{Eq. 2-1}$$

where $t_z$ is the deadtime and $T_v$ is the period of the voltage.

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[8] Mohamad H, etal, “A review on islanding operation and control for distribution network connected with small hydro power plant,” *Renew Sustain Energy Rev,* 2011, pp.3952–3962.

[9] A. Massoud, K. Ahmed, S. Finney, B. Williams, “Harmonic distortion-based island detection technique for inverter-based distributed generation”, *IET Renewable Power Generation*, no. 3, vol. 4, 2009, pp. 493-507.

[10] M. Ropp, M. Begovic, A. Rohatgi, “Analysis and Performance Assessment of the Active Frequency Drift Method of Islanding Prevention”, *IEEE Transactions on Energy Conversion,* no.14, vol. 3, September 1999, pp. 810-816.

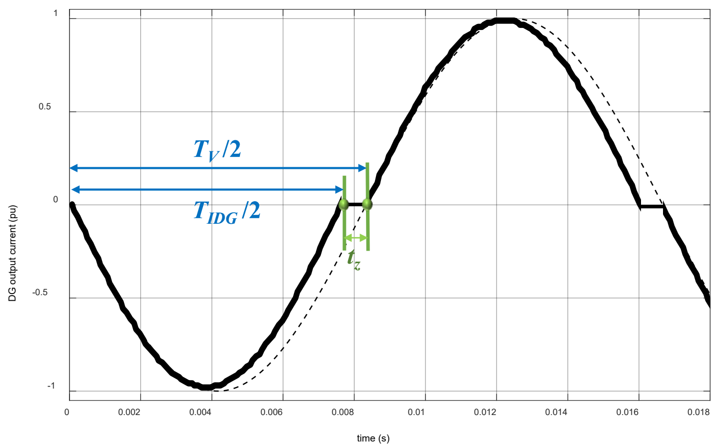


**Figure 2-3**
**DG output current using AFD.**

*Slip-mode frequency shift (SMS)* – This method changes the phase angle of DG output current injected into PCC, through positive feedback, as expressed in (Eq. 2-2). During grid connection, system frequency will be clamped by grid and stay stable. However, during grid disconnection, the phase angle and thus frequency will be upset by the perturbation and go outside its acceptable limits, hence trip the DG through UOF protection.

$$\theta = \theta_m \sin(\frac{\pi}{2}\frac{f^{k-1} - f_n}{f_m - f_n}) \qquad \textbf{Eq. 2-2}$$

where $\theta_m$ is the maximum allowed phase angle at the frequency $f_m$, $f_n$ is the rated frequency, and $f^{k-1}$ is the frequency in the previous cycle.[11]

*Active phase shift (APS)* – Introducing an additional phase shift to SMS, which can break the stable operation of frequency and ensure effective UOF trips.

*Active frequency drift with positive feedback (AFDPF)* – This method utilizes a positive feedback to increase the chopping fraction of AFD, as expressed in (Eq. 2-3). It can improve the effectiveness of AFD in multiple inverter applications and reduce the NDZ.

$$cf_k = cf_{k-1} + F(\Delta\omega_k) \qquad \textbf{Eq. 2-3}$$

where $cf_k$ and $cf_{k-1}$are the chopping fractions of the kth and k-1th cycles, $\Delta\omega_k$=$\omega_k - \omega_{k-1}$, and F is typically a linear function.

*Sandia frequency shift (SFS)* – Similar to AFDPF, this method varies the frequency of PCC voltage through positive feedback on chopping fraction, which is given in (Eq. 2-4).

$$cf = cf_0 + K(f_{pcc} - f_{grid}) \qquad \textbf{Eq. 2-4}$$

[11] Liu F, Kang Y, Zhang Y, Duan S, Lin X, "Improved SMS islanding detection method for grid-connected converters," *IET Renew Power Generation*, 2010, no. 4, vol. 1, pp. 36–42.

where $cf_0$ is the chopping factor when frequency has no deviation, K is the accelerating gain, $f_{pcc}$ and $f_{grid}$ are the frequency at PCC and the grid. During grid disconnection, the chopping fraction increases and produces frequency elevation as well as phase error. In order to compensate the phase error, the inverter will iterate this process until exceeding the UOF threshold.[12]

*Sandia voltage shift (SVS)* – This method varies the inverter output current based on the PCC voltage, through positive feedback. During grid connection, the voltage will be clamped by grid and stay stable. During grid disconnection, the inverter output current increases (decreases) when voltage magnitude increases (decreases), which in turn elevates (reduces) the voltage until trips the DG because of under/over voltage (UOV) protection.

*Frequency jump (FJ)* – This method adds dead zones into the wave of DG output current every second or third cycle. During grid connection, the voltage will be stable and not affected by the distorted current. During grid disconnection, however, both the voltage and current will change as programmed by the inverter. The DG will trip if the system frequency is modified, or the voltage matches the specific designed pattern.

*General Electric frequency schemes (GEFS)*[13] – This method adjusts the inverter's output power, and trip it if the variation in voltage magnitude and/or frequency exceeds the preset threshold.

*Negative-sequence current injection* – This method utilizes positive feedback on negative-sequence current injection, and trip the DG if the negative-sequence voltage at PCC exceeds the threshold.

*Mains monitoring units with allocated all-pole switching devices connected in series (MSD) (Also called ENS)* – In this method, two independently controlled all-pole switching devices are connected in series to monitor the grid status and automatically isolate the DG when island occurs. This method can be used for multiple islanding detection methods, e.g. impedance detection with UOV and UOF trips.[6]

Compare to the passive techniques, active IDMs greatly reduce the NDZ and have higher detection accuracy. However, in order to inject the perturbation, control equipment and/or power electronic devices are required, which increases the implementation cost and complexity. In addition, the perturbation introduced by active IDMs may degrade the power quality, and take a long time to upset the system parameters, leading to a relatively long detection time.

[12] Zeineldin HH, Kennedy S, "Sandia frequency-shift parameter selection to eliminate nondetection zones," *IEEE Trans on Power Deliver*, 2009, no. 24, pp. 486–497.

[13] Z. Ye and M. Dame, "Grid-connected inverter anti-islanding test results for general electric inverter-based interconnection technology," January 2005.

## 2.3 Hybrid Techniques[14]

Hybrid IDMs combine the features of both passive and active techniques. During islanding operation, the passive IDM functions primarily, and active technique serves as back up and only activates when the detection criteria of passive IDM are met. The operating principle of prevailing hybrid techniques are summarized below, with their key metrics listed in Table 2-3**.**

*Technique based on positive feedback (PF) and voltage unbalance (VU)* – This method monitors the voltage unbalance, and activates the positive feedback schemes (active technique) to disturb the frequency or voltage magnitude if the VU exceeds the threshold.

*Technique based on voltage and reactive power shift* – This method detects the rate of change of voltage, and if it exceeds the threshold, activates the reactive power shift (active technique) to disturb the frequency.

*Technique based on voltage and real power shift* – This method detects the rate of change of voltage, and if it exceeds the threshold, activates the real power shift scheme (active technique) to disturb the voltage / frequency. This method can be utilized for DG units that have to operate at a unity power factor.

*Technique based on local measurements and high frequency component evaluation* – This method detects the abnormal local measurements at PCC, e.g. voltage and frequency, to activate the high frequency component injection and evaluation.

*Hybrid SFS and Q–f islanding technique* – This method adds Q – f droop curve to the SFS for improved islanding detection performance. The SFS is optimized to eliminate NDZ, and Q – f characteristics of both DG and loads are selected such that the DG can operate stably during grid connection while become instable when disconnects from the grid.[15]

*Hybrid SMS and Q-f islanding technique* – This method adds Q – f droop curve to the SMS for improved islanding detection performance.

*Combination of RoCoF and IM* – This method uses RoCoF as primary protection and IM as the backup.

Since the active methods in the hybrid IDMs only operate when the passive ones identify the possibility of islanding, the level of perturbation and power quality degradation can be minimized. In addition, by introducing the active method, the power balance that cannot be detected by passive one will be broken, thus enabling a smaller NDZ. Consists of both active and passive IDMs, however, the hybrid techniques take longer time than the passive ones to detect the islanding events.

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[14] S. Raza, etal, "Application of signal processing techniques for islanding detection of distributed generation in distribution network: A review," *Renewable and Sustainable Energy Reviews*, vol. 96, 2015, pp. 613 – 624.

[15] Vahedi H, Noroozian R, etal, "Hybrid SFS and Q–f islanding detection method for inverter-based DG," *IEEE international conference on power and energy*, 2010, pp. 672–676.

## 2.4 Computational Intelligence Techniques[16]

The popular computational intelligence (or intelligent classifier) based IDMs are summarized below and compared in Table 2-4, which normally combines with various signal processing techniques for enhanced efficiency, high accuracy and fast detection speed. In addition, these IDMs can detect the islanding events without any threshold selection, as in the case of passive and active methods, reducing the design complexity.

*Artificial neural network (ANN)* – This method uses a computational structure model in which all the useful information and data memory are contained in a brain.[17] For power system issues, multilayer feed forward networks are commonly utilized, where system data is measured to identify any changes.

*Probabilistic neural network (PNN)* – This method relies on a Bayesian classifier technique, which is used in classical pattern recognition applications.[18] It consists of four layers: input, pattern, summation and output. Each layer has its unique function to classify the features of voltage, frequency, energy, etc. Learning process is not required for this method.

*Artificial immune system (AIS)* – This method consists of two modules: T-module and B-module. T-module is used for islanding condition detection, and B-module is employed to enlarge the detection coverage space.[19]

*Decision trees (DT)* – Decision tree learning is an approach to approximate the discrete-valued target functions, where the learned functions are represented by decision trees.[20] In this method, each branch corresponds to one possible value. The training could start at the root node of the tree and then move down to test other attributes specified by their corresponding nodes. This process will be repeated to identify the best attribute to test in the tree.

*Fuzzy logic (FL)* – Fuzzy Logic represents the expert human knowledge in the form of fuzzy rules. A typical fuzzy inference system consists of four functional blocks: 1) knowledge base including the rule base and data base; 2) a decision-making unit conducting the inference operations on the fuzzy rules; 3) fuzzification inference transforming the crisp inputs into results that match with linguistic values; 4) a de-fuzzification inference converting the fuzzy results into a crisp output.[21]

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[16] A. Khamis, etal, “A review of islanding detection techniques for renewable distributed generation systems,” *Renewable and Sustainable Energy Reviews*, vol. 28, 2013, pp. 483 – 493.

[17] Z. Guan, “A new islanding detection method based on wavelet-transform and ann for inverter assisted distributed generator,” Theses and dissertations, University of Kentucky, 2015.

[18] A. Khamis, H. Shareef, etal, “Islanding detection in a distributed generation integrated power system using phase space technique and probabilistic neural network,” *ELSEVIER, Neurocomputing*, 2015, pp. 587-599.

[19] L. de Castro and J. Timmis, "Artificial Immune Systems: A Novel paradigm to Pattern Recognition", *Artificial Neural Networks in Pattern Recognition*, SOCO-2002, University of Paisley, UK, 2002.

[20] M. Thomas, P. Terang, "Islanding detection using decision tree approach. Power Electronics", *Drives and Energy Systems (PEDES)*, 2010, pp.1–6

[21] S. Samantaray, K. El-arroudi, G. Joós, I. Kamwa, "A fuzzy rule-based approach for islanding detection in distributed generation", *IEEE Transaction on Power Delivery*, 2010, pp.1427–1433.

## 2.5 Remote Techniques

Remote islanding detection techniques in Table 2-5 and Table 2-6 rely on communication between utility and DERs. [22] In these methods, the status of PCC switch is continuously monitored and once an islanding event occurs, a trip signal is transmitted to DERs or a low impedance is inserted.

### *A. Communication base remote islanding detection method*

*Phasor measurement units (PMU)* – Rely on the time synchronization source in PMU to detect the synchronization between DG and the grid.

*Comparison of rate of change of frequency (CoRoCoF)* – Monitor the change of frequency (RoCoF) at both grid and DG side. DG will trip at two conditions: 1) if the RoCoF value at grid side exceeds a preset threshold, a block signal will be sent to the DG; 2) no block signal received, while the RoCoF value measured at DG side exceeds the threshold.

*Supervisory control and data acquisition system (SCADA*) – This method utilizes the wide communication network and advanced sensors to monitor the system's status.[23] During grid disconnection, the abnormal frequency and voltage information will be sent to control center for islanding detection.

*Power line carrier communication (PLCC)* – This method consists of one transmitter placed near the grid PCC switch and a receiver at the DG side.[24] Under normal condition, the transmitter continuously sends a low energy signal, which will be detected by the receiver to keep the DG online. The PLCC signal will not be sent during grid disconnection, and the DG will cease to energize if such signal is not detected for certain time, e.g. typically three consecutive periods.

*Transfer tripping scheme (TTS)* – This method monitors the status of all devices that could cause the island, such as breakers and reclosers. Once the grid disconnection is detected, TTS will send appropriate signals to the DG to either maintain operating or disconnect from the grid.[25]

*Signal produced by disconnect (SPD)* – Similar to PLCC, this method utilizes communication to detect the islanding. But in this case, mainly microwave link or telephone line are used as communication medium. DG trips when the switch connects to the grid is open.[26]

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[22] K. N. E. K. Ahmad, etal, "A review of the islanding detection methods in grid-connected PV inverters," *Renewable and Sustainable Energy Reviews*, vol. 21, 2013, pp. 756 – 766.

[23] I. Pvps, "Evaluation of islanding detection methods for photovoltaic utility interactive power systems," *Report IEA PVPS T5-09*, 2002.

[24] W. Xu, G. Zhang, etal, "A power line signaling based technique for anti-islanding protection of distributed generators—Part I: scheme and analysis," *IEEE Trans on Power Delivery,* 2007, pp:1758–1766.

[25] J. Yin, etal, "Recent developments in islanding detection for distributed power generation," *Large engineering systems conference on power engineering*; 2004, pp. 124–128.

[26] I. J. Balaguer, H.-G. Kim, F. Z. Peng, and E. I. Ortiz, "Survey of photovoltaic power systems islanding detection methods," *IEEE Trans on Industrial Electronics*, 2008, pp. 2247-2252.

### *B. Utility islanding detection method*

*Impedance insertion* – In this method, a low impedance (usually a capacitor bank) is inserted on the grid side to detect the potential island. [27] For example, in Figure 2-4, when the switch BK1 opens, the switch BK2 closes after certain time delay and insert the capacitor bank into the islanded system. The inserted capacitor will create a sudden change in phase angle and frequency, disrupting the potential power balance and tripping the DG.

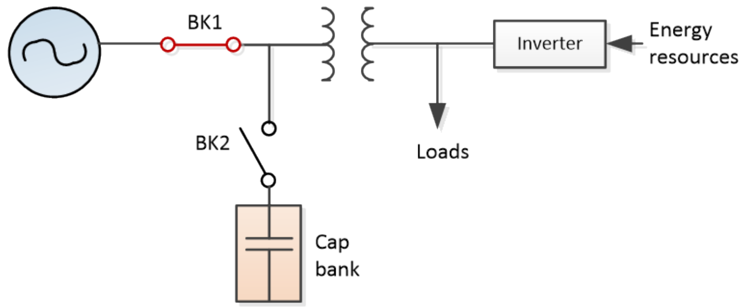



**Figure 2-4**
**Impedance insertion based islanding detection.**

The advantages of remote techniques include zero NDZ, fast response, high reliability, and no degradation on power quality and system transients. In addition, the remote techniques remain effective, despite of the type, number and size of DGs, and penetration level. The drawbacks are complex communication network and expensive implementation, especially for small scale systems.

## 2.6 Conclusions

This chapter presents a comprehensive review on the state-of-the-art islanding detection methods, which can be categorized into two main groups: inverter on-board techniques and utility-controlled islanding preventions. The inverter on-board techniques, consist of passive, active, hybrid, computational intelligence based methods, are implemented in DER side. The utility-controlled islanding preventions are on the grid side and rely on tight communication. Their operation principles and detection performance are briefly introduced, including non-detection zone, typical detection time, and impact on power quality. The strength and weakness of each method are also summarized. In general, the remote detection technique can eliminate the NDZ, but at the cost of expensive communication network as well as complex implementation. For small scale DER systems, inverter on-board islanding detection techniques provide a better cost-benefit performance.

[27] C. Trujillo1, D. Velasco, "Local and remote techniques for islanding detection in distributed generators,"2010.

**Table 2-1**
**Passive islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 1 | Rate of change of Power (ROCOP) | Smaller than UOV/UOF | 24-26 ms | No impact | 1. No detection speed degradation when power mismatch between DG generation and loads within the island is small<br>2. Unsynchronized reclosing of the grid to the DG can be quickly detected<br>3. High effectiveness for unbalanced loads | 1. Still has NDZ when power between DG generation and loads is closely matched. Effectiveness will improve when power imbalance increases<br>2. Difficult trip setting selection |
| 2 | Rate of change of frequency (ROCOF) | Small | 24 ms | No impact | 1. Higher sensitivity and faster detection speed than UOV/UOF<br>2. High detection effectiveness and fast speed even when power between DG generation and loads is closely matched | 1. Difficult threshold selection<br>2. Susceptible to mal-operation, since it cannot distinguish the causes of frequency variation (e.g. islanding or load changes) |
| 3 | Rate of change of frequency over power (ROCOFOP) | Smaller than ROCOF | 100 ms | No impact | 1. High reliability<br>2. Smaller NDZ than ROCOF. Higher detection effectiveness for small power mismatch applications | |
| 4 | Rate of change of voltage (ROCOV) | Large | | No impact | 1. Easy implementation<br>2. Fast response | 1. NDZ is closely coupled with the system disturbances<br>2. Difficult threshold selection |
| 5 | Rate of change of phase angle difference (ROCOPAD) | Large | | No impact | 1. Can detect islanding condition with a small power mismatch<br>2. Fast response | 1. Sensitive to fluctuation and load switching, which may lead to error detection<br>2. Difficult threshold selection |
| 6 | Voltage Unbalance | Large | 53 ms | No impact | 1. High immunity to load fluctuation<br>2. Not sensitive to system disturbances | 1. Extraction accuracy of negative sequence voltage may be affected by distortion<br>2. Difficult threshold selection |

**Table 2-1 (continued)**
**Passive islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 7 | Over/Under voltage & Under/Over frequency | Large | From 4 ms to 2 s | No impact | Low implementation cost since utilities use the same method to protect loads and equipment from damage | 1. Large NDZ<br>2. Reaction time of protection equipment varies, leading to a difficult detection time prediction |
| 8 | Detection of voltage and/or current harmonics | Large with a high value of Q | 45 ms | No impact | 1. Easy implementation<br>2. Fast detection speed for a wide range of applications | 1. Difficult threshold selection<br>2. Large NDZ when load has a high quality factor<br>3. Detection effectiveness may degrade for system with multiple DGs<br>4. Prone to fail when island system does not have transformer(s) and/or output of inverters has low distortion |
| 9 | Phase jump detection | Smaller than UOV/UOF | 10- 20 ms | No impact | 1. Easy implementation<br>2. Fast detection speed<br>3. Effectiveness does not degrade for multiple DGs | 1. Difficult threshold selection since phase jump could also be caused by load switching, especially motor load<br>2. Large NDZ. Prone to fail if local loads, e.g. resistive load, cannot produce sufficient phase error |
| 10 | Detection based on state estimators | Small | | No impact | 1. Very low NDZ<br>2. High detection effectiveness<br>3. Fast detection speed | Complicated programming techniques |

**Table 2-2**
**Active islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 1 | Reactive power export error detection (RPEED) | | 2 s - 5 s | | More effective than passive methods when dealing with a small power mismatch | 1. Slow detection speed<br>2. Not applicable to DGs that have to operate with unity power factor |
| 2 | Impedance measurement (IM) | Small NDZ for single DG | 0.77 s - 0.95 s | Produce harmonics | Small NDZ for any given single inverter | 1. Ineffective for multiple DGs, unless they operate synchronously<br>2. Difficult threshold selection since accurate value of grid impedance is required |
| 3 | Detection of impedance at specific frequency or harmonic injection | NDZ can be eliminated by injecting a sub-harmonic | | Produce more harmonics | Highly effective in detecting islanding | 1. Difficult threshold selection<br>2. Ineffective for multiple DGs |
| 4 | Active frequency drift (AFD) | Increases when load quality factor increases same NDZ as SMS if the chopping fraction is small (< 1%) | Within 2 s | Degrade | 1. Easy implementation for a microprocessor – based DG<br>2. Small NDZ, and no NDZ for resistance load | 1. Power quality degradation<br>2. NDZ is closely related to chopping factor<br>3. Effectiveness reduces for multiple DGs if their deviations on frequency bias are different<br>4. Effectiveness is highly affected by load parameters. For non-resistance loads, the detection time and NDZ increases with higher quality factor |

**Table 2-2 (continued)**
**Active islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 5 | Slip-mode frequency shift (SMS) | Smaller than AFD. Large for load with high quality factor | About 0.4 s | Affect system transient stability | 1. Small NDZ<br>2. Easy implementation<br>3. Highly effective for multiple DGs 4. A good compromise between detecting effectiveness, power quality and system transient stability [28] | 1. May degrade system power quality and transient stability<br>2. Relatively low stability with high penetration levels and high feedback loop gain |
| 6 | Active phase shift (APS) | Smaller than SMS | | | 1. Highly effective for multiple DGs<br>2. Effective for parallel RLC loads with resonant frequency equals to the line frequency[29] | Effectiveness reduces for loads with large inertia |
| 7 | Active frequency drift with positive feedback (AFDPF) | Smaller than AFD | | Slightly degrade | 1. Improved performance if compared to AFD, and greatly reduced NDZ<br>2. Low sensitivity on load parameters | 1. Slight power quality degradation<br>2. Remaining NDZ for loads with high quality factor |
| 8 | Sandia frequency shift (SFS) | Smallest | Within 0.5s | Slightly degrade | 1. One of the schemes enabling smallest NDZ<br>2. High effectiveness when coupled with Sandia Voltage Shift<br>3. A good compromise between detecting effectiveness, power quality and system transient stability | 1. Slight degradation on system power quality and transient stability<br>2. Susceptible to noises and harmonics |

[28] P. Mahat, Z. Chen, B. Bak-jensen, "Review on islanding operation of distribution system with distributed generation," *Power and energy society general meeting,* 2011, pp. 1–8.

[29] R. Kunte, W. Gao, "Comparison and review of islanding detection techniques for distributed energy resources," *North American power symposium*,2008, pp. 1–8.

**Table 2-2 (continued)**
**Active islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 9 | Sandia voltage shift (SVS) | Smallest | | Slightly degrade | 1. Easy implementation<br>2. High detection effectiveness when coupled with SFS | 1. Slight degradation on system power quality and transient response<br>2. Needs to change inverter's output active power, hence affects the maximum power point tracking (MPPT) algorithm of PV inverter and reduces the energy efficiency |
| 10 | Frequency jump (FJ) | Almost no NDZ for single inverter | | Degrade | 1. Effective if sophisticated frequency deviation scheme is used<br>2. For single inverter, NDZ is almost zero | Ineffective for multiple DGs if frequency dithering function is not synchronized |
| 11 | GE frequency schemes (GEFS) | Small | 0.3 s – 0.75 s | Degrade | 1. Easy implementation<br>2. No NDZ<br>3. Low cost<br>4. Robust to grid disturbances | 1. Effectiveness may degrade for multiple DGs<br>2. Degradation on system power quality and transient response since this method continuously change the inverter's output |
| 12 | Negative-sequence current injection | Very small | 60 ms | | 1. Fast detection speed<br>2. Not sensitive to load change<br>3. Higher accuracy than detecting positive-sequence voltage variation | Degradation on system power quality |
| 13 | Mains monitoring units with allocated all-pole switching devices connected in series (MSD). Also called (ENS). | Very small for single system | | | 1. Enhanced reliability due to the redundant design and automatic self-test<br>2. Easy system implementation and maintenance | Ineffective for multiple DGs due to the interference between ENS units |

**Table 2-3**
**Hybrid islanding detection methods**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 1 | Technique based on positive feedback (PF) and voltage unbalance (VU) | Very small | | Reduced negative impact if compared to PF methods, e.g. SFS, SVS, etc. | 1. Reduced negative impact on system transient response, especially for multiple DGs, if compared to PF methods<br>2. Higher effectiveness if compared to VU | |
| 2 | Technique based on voltage and reactive power shift | Small | | Small | Improved power quality and detection effectiveness if compared to the two methods applied separately | |
| 3 | Technique based on voltage and real power shift | Small | | Small | Improved power quality and detection effectiveness | Affect system transient stability and DG efficiency since this method continuously change the DG's output |
| 4 | Technique based on local measurements and high frequency component evaluation | | | Produce more harmonics | Reduced negative impact on power quality, if compared to active harmonic injection methods | Ineffective for multiple DGs |
| 5 | Hybrid SFS and Q–f islanding technique | Smaller than SFS | | | Reduced control complexity since a simple method such as UOF is sufficient for islanding detection | |
| 6 | Hybrid SMS and Q-f islanding technique | Smaller than SMS | | | Reduced control complexity | |
| 7 | Combination of RoCoF and IM | Small | 0.216 s | | 1. Higher effectiveness than RoCoF since it can discriminate islanding and other disturbances<br>2. Faster detection speed than IM | |

**Table 2-4**
**Computational intelligence base islanding detection methods**

| No. | IDM | Non-detection Zone | Strength | Weakness |
|---|---|---|---|---|
| 1 | Artificial neural network (ANN) | Very small | High detection accuracy | |
| 2 | Probabilistic neural network (PNN) | Very small | Effective and reliable islanding detection | |
| 3 | Artificial immune system (AIS) | Very small | Effective and accurate islanding detection | |
| 4 | Decision trees (DT) | Very small | | Not always effective and can be improved with other optimization methods |
| 5 | Fuzzy logic (FL) | Very small | | 1. Highly abstract, and requires experts for rule discovery<br>2. Complex due to the incapability of self-organization and self-tuning |

**Table 2-5**
**Communication base remote islanding detection method**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 1 | Phasor measurement units (PMU) | None | | None | | |
| 2 | Comparison of rate of change of frequency (CoRoCoF) | Smaller than ROCOF | Very small | Low | 1. High reliability<br>2. High detection accuracy<br>3. Smaller NDZ than RoCoF | Difficult implementation because of:<br>1. much computation is involved;<br>2. communication between grid and DG |
| 3 | Supervisory control and data acquisition system (SCADA) | None | Detection speed is slow if systems are busy | None | 1. Knowing local information, the utility operator can partially or fully participate the DG control<br>2. No NDZ exists if proper infrastructure and communications links are available | 1. High implementation cost due to large number of sensors and communication links, and thus may not be economical for small DG systems<br>3. Slow detection speed, especially in a busy communication system |

**Table 2-5 (continued)**
**Communication base remote islanding detection method**

| No. | IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|---|
| 4 | Power line carrier communication (PLCC) | Without NDZ for normal loads | 200 ms | None | 1. High detection accuracy<br>2. High effectiveness for multiple DGs<br>3. Existing PLCC signals can be utilized for other purposes | 1. High implementation cost for transmitter and receiver, and would not be economical for small DG systems<br>2. NDZ may exist because of the signaling error |
| 5 | Transfer tripping scheme (TTS) | None if properly implemented | | None | 1. Simple if the system has radial configuration and low number of DGs and breakers<br>2. High detection accuracy if correctly implemented | High cost for necessary update and reconfiguration when system grows and becomes complex[30] |
| 6 | Signal produced by disconnect (SPD) | None | 100 - 300 ms | None | 1. Provide coordination between the DG and grid, enabling efficient system management and additional supervision<br>2. Effective for multiple DGs | 1. High cost if telephone line is used as communication medium<br>2. Complex design and permitting complications, e.g. microwave links may require license from relevant commissioning authority[31] |

[30] EPRI whitepaper, "Are Current Unintentional Islanding Prevention Practices Sufficient for Future Needs?" 3002003291, Feb. 2015.

[31] B. Yu, M. Matsui, G. Yu, "A review of current anti-islanding methods for photovoltaic power system," *Solar Energy*, 2010, pp.745–754.

**Table 2-6**
**Utility islanding detection method**

| IDM | Non-detection Zone | Typical Detection Time | Impact on Power Quality | Strength | Weakness |
|---|---|---|---|---|---|
| **Impedance insertion** | None | | Highly effective | 1. High effectiveness if the delay of capacitor insertion is small enough<br>2. Low implementation cost if the capacitors are already in use<br>3. No NDZ if properly implemented | 1. High implementation cost if extra capacitor banks are needed<br>2. Switches for capacitor disconnection may lead to additional islanding branches<br>3. Much longer detection and execution time<br>4. Equipment needs to be installed on the grid side, requiring additional permits and costs. |

# 3

# INVERTER MANUFACTRUER SURVEY RESULTS

## 3.1 Overview and Objectives

Applicable grid codes and standards, such as IEEE 1547[32,33], require that DERs shall detect an unintentional island and cease to energize within 2 seconds. Longer duration of unintended islanding is considered to be problematic. In order to meet these requirements, on-board islanding detection methods, as introduced in section 2, have been implemented in recent commercial DER inverters. Aiming at identifying the most popular islanding detection methods (IDMs) adopted in the real world, EPRI initiated an effort to develop a survey and provided to 27 major DER manufacturers. The survey response will serve as a basis of generic response model development.

In total, 17 responses were received, among which 13 participants were willing to release their information, while the others preferred to be anonymous. The 13 participants include ABB, Bloomenergy, Chint Power SystemEnphase, Ingeteam, Huawei Technologies, Schneider, SMA, Solaredge, Sunpower, TMEIC, Tabuchi, and Powerhub, covering most of the major DER inverter manufacturers.

This chapter will summarize the survey results, identify islanding detection schemes used in real-world, and convey the current DER inverter manufacturer thinking, including the most promising anti-islanding preventions as well as anticipated updated to comply with the new IEEE 1547 standard, to mitigated islanding risk with minimum cost in the future.

## 3.2 Survey Questions and Results

**Question 1**: **In your company, islanding detection methods are implemented for 1) PV inverter; 2) Energy storage (ES) inverter; 3) Wind turbine (WT) inverter; or 4) Other.**

**Purpose:** Ascertain the DER products from the company of survey respondents, and take this into consideration when interpreting survey results.

**Results:** Out of 17 respondents, the majority have IDMs implemented in PV inverters (88.24%) and ES inverters (64.71%). The IDMs are also available in WT, fuel cell inverters and EV chargers, but with relatively low percentage. This may occur because the survey invitation was mainly sent to well-known PV and ES inverter manufacturers. It also worth mentioning that each participant could have multiple types of DER inverters manufactured in his/her company, leading to a sum of percentage (for all options) higher than 100%.

[32]IEEE Standard 1547-2003, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems", July 2003.

[33] IEEE Standard 1547-2018, "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces", February 2018.

**Figure 3-1**
**Types of DER inverters that implement islanding detection methods (17 respondents)**

**Question 2**: **Any certification (global) required for the DER inverter 1) UL1741; 2) IEC62116; or 3) Other.**

**Purpose:** Find out the certifications manufacturers comply with for DER inverters.

**Results:** All of the 17 respondents confirmed their compliances to IEEE 1741, and slightly over half of them also comply with IEC62116. Two respondents stated their unique approaches to certify the DER inverters (as Category "other"), and quoted here:

1. "Few special requirements from international customers/utilities. We submit our own lab report. No third-party testing agency certification is required."
2. "UL 9741"

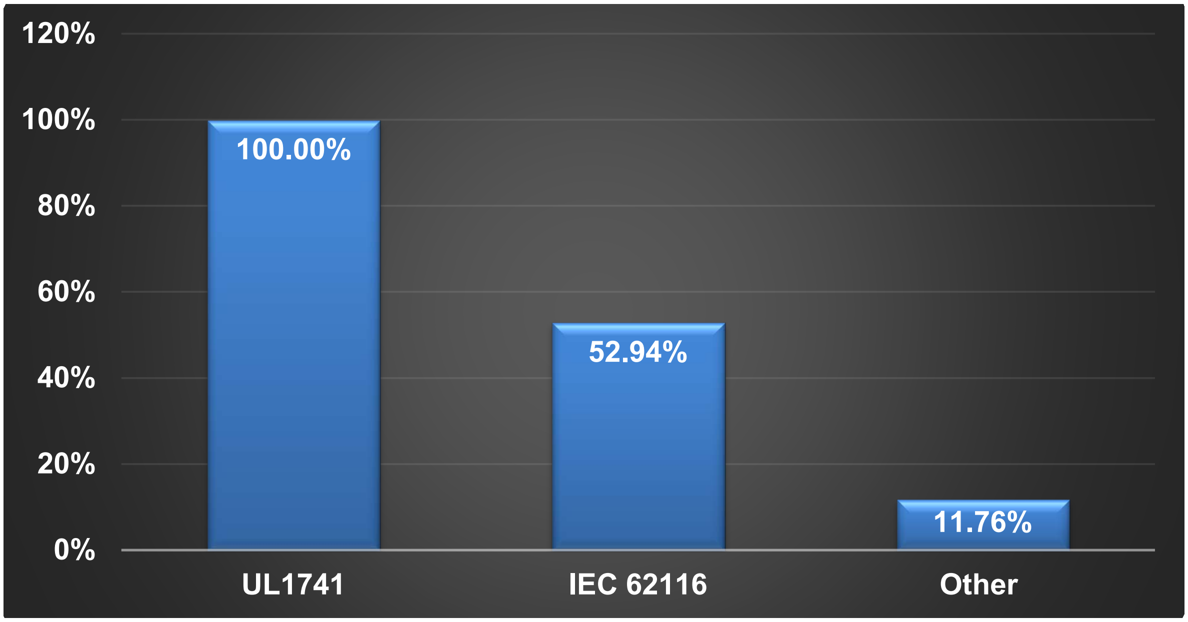



**Figure 3-2**
**Certification compliance (17 respondents)**

**Question 3**: **If known, what type of islanding detection method is supported by the DER inverters from your company?**

**Purpose:** Illustrate how widespread each type of islanding detection method is among DER inverters manufactured by respondents.

**Results:** Passive and active methods are two dominate techniques for islanding detection (58.8% and 76.5% respectively), while hybrid methods (29.4%) and computational intelligence based methods (17.7%) are available in commercial DER inverters, but with relatively low percentages. One exception was provided, as quoted here, "Proprietary method for aggregated inverts - example utility scale project with hundreds of string inverts in parallel on a single site". This falls into the category "other". Note here several respondents selected more than one options, and thus the sum of all options is higher than 100%.

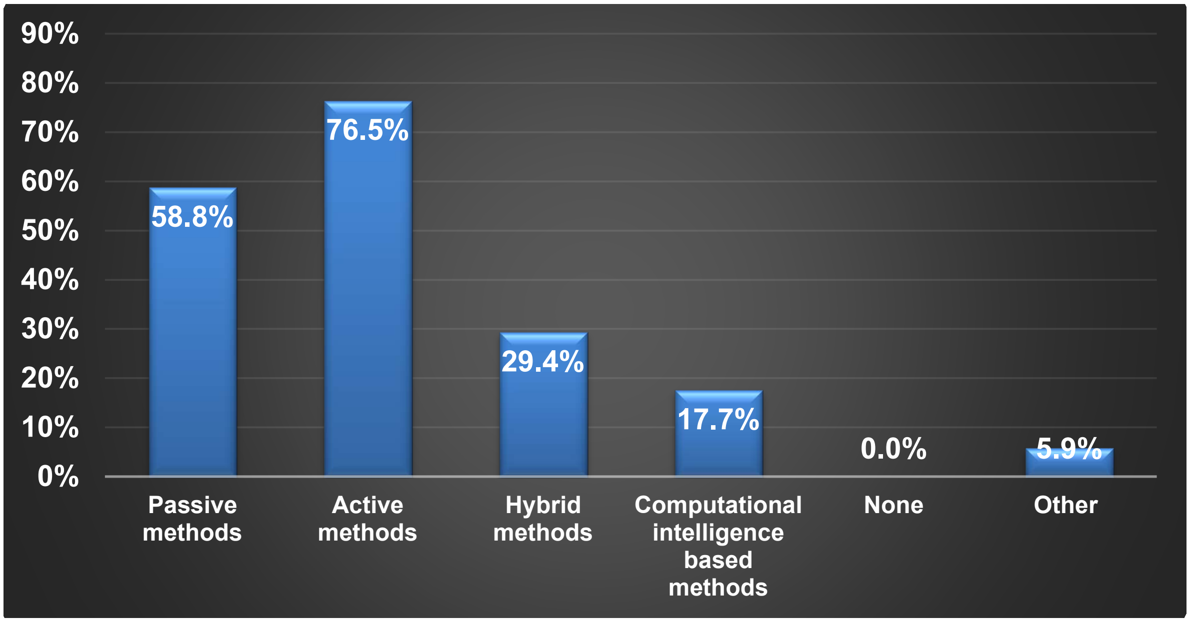



**Figure 3-3**
**Types of islanding detection method (17 respondents)**

**Question 4**: **If applicable, what PASSIVE abnormal condition detection method(s) (or similar) are available in the DER inverters from your company?**

**Purpose:** Illustrate how widespread each passive islanding detection technique is among DER inverters manufactured by respondents.

**Results:** One respondent skipped this question. For the remainder, rate of change of frequency/voltage/power (75%) and Over/Under voltage & Over/Under frequency (81.3%) are the two dominate techniques for passive islanding detection, followed by phase jump (50%) and voltage unbalance (43.8%). Adoption of harmonics based detection methods is relatively low (25%). In the category "other", two respondents indicated that other passive methods may exist, but they were unware of the details.

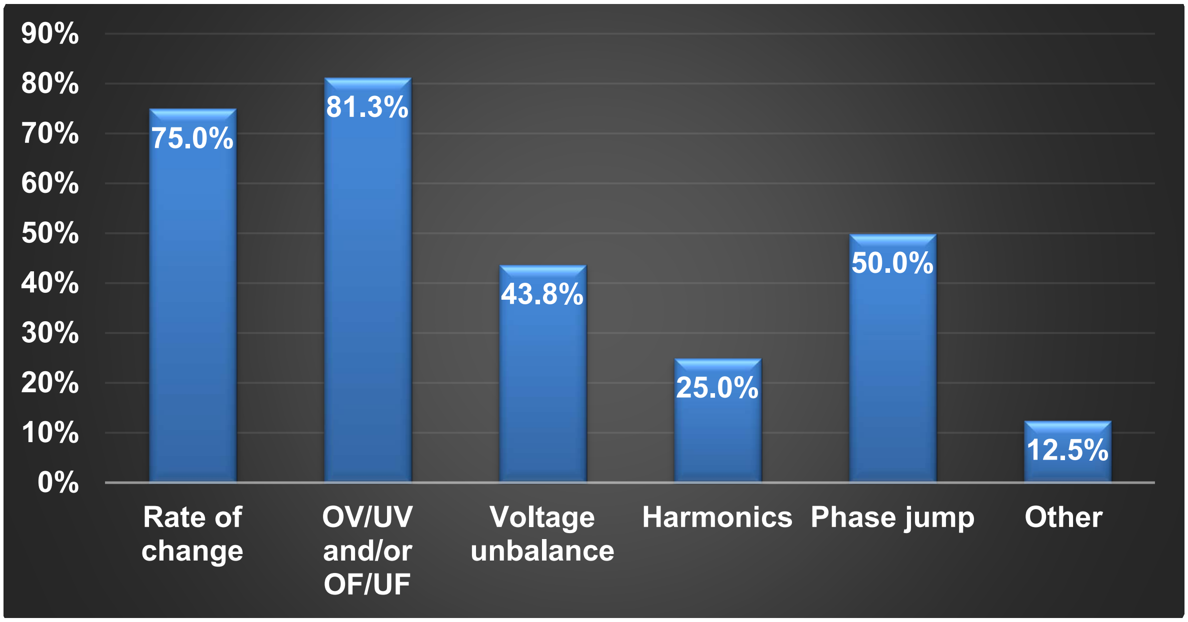


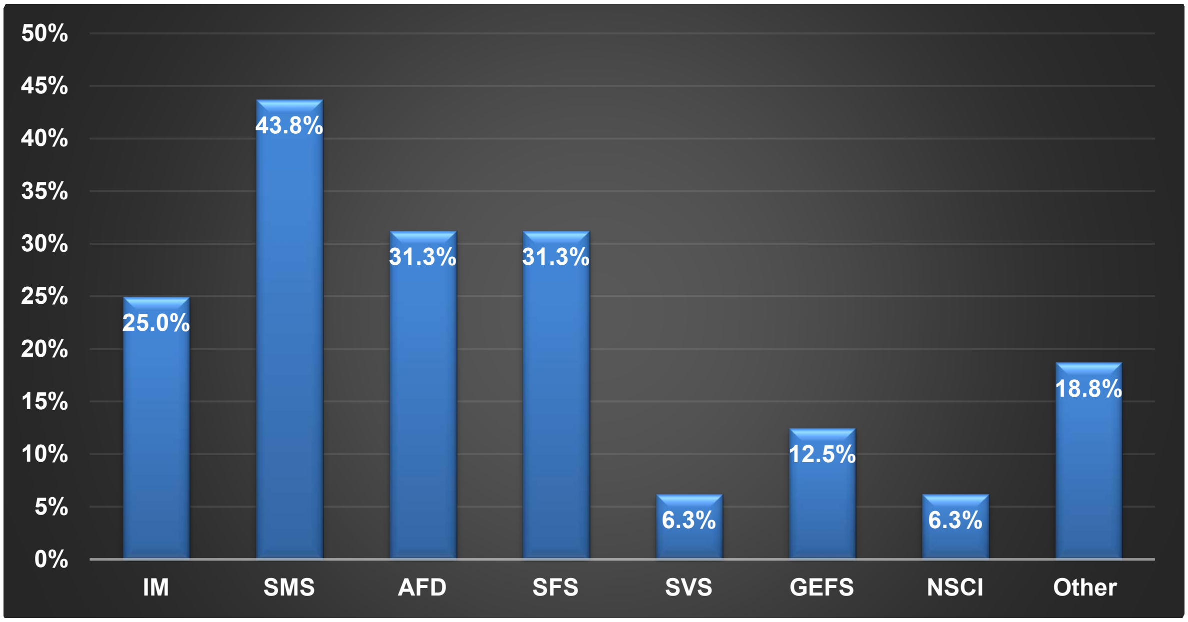

**Figure 3-4**
**Passive islanding detection methods (16 respondents)**

**Question 5**: **If applicable, what ACTIVE islanding detection method(s) (or similar) are available in the DER inverters from your company?**

**Purpose:** Illustrate how widespread each active islanding detection technique is among DER inverters manufactured by respondents.

**Results:** One respondent skipped this question. Out of the remaining16 respondents, nearly half (43.8%) adopt the slip-mode frequency shit (SMS) method for islanding detection. Active frequency drift (AFD, 31.3%), Sandia frequency shift (SFS, 31.3%) and impedance measurement (IM, 25%) are another three techniques that are widely utilized, and the remainders (SVS, GEFS, NSCI) are relatively less used according to the received responses. Two respondents stated their unique techniques: 1) Frequency shift method similar to the SFS method. Reactive power injection is used to perturb frequency; 2) Active voltage phase change detection.

It worth mentioning that SMS, AFD and SFS are all rely on the positive feedback of frequency deviation, and perturb the angle or power output accordingly. This will finally push the frequency out of its normal operation range, and trip the DER inverters through Under/Over frequency protection.



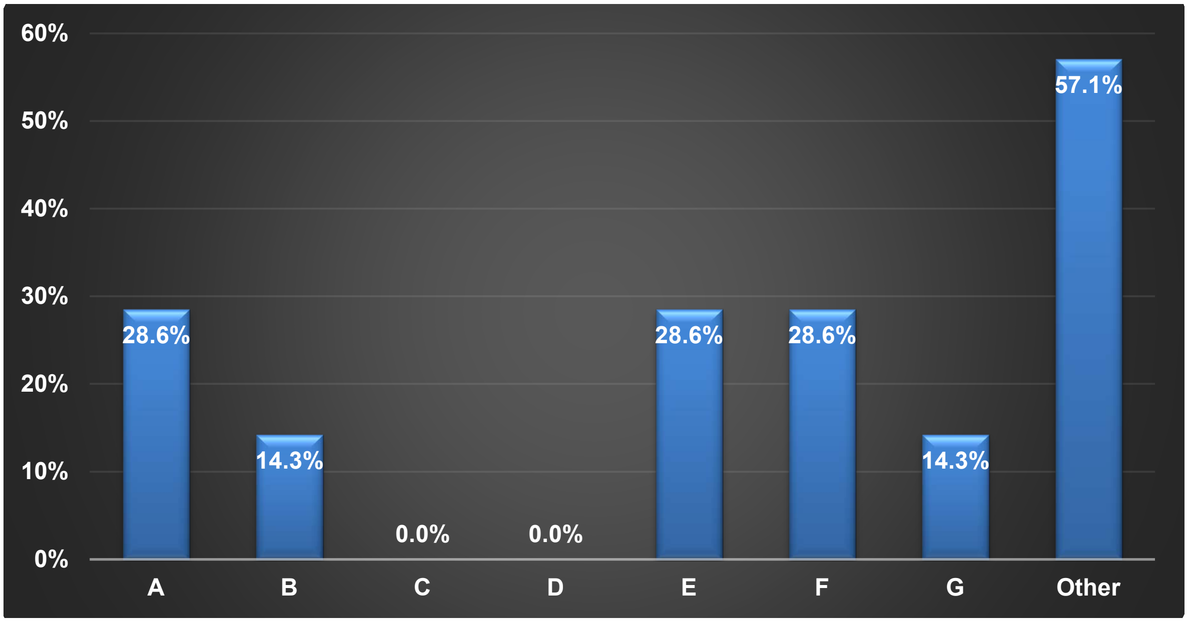

| | |
|---|---|
| IM | Impedance measurement (IM) |
| SMS | Slip-mode frequency shift (SMS) |
| AFD | Active frequency drift (AFD) |
| SFS | Sandia frequency shift (SFS) |
| SVS | Sandia voltage shift (SVS) |
| GEFS | GE frequency schemes |
| NSCI | Negative-sequence current injection |

**Figure 3-5**
**Active islanding detection methods (16 respondents)**

**Question 6**: **If applicable, what HYBRID islanding detection method(s) (or similar) are available in the DER inverters from your company?**

**Purpose:** Illustrate how widespread each hybrid islanding detection technique is among DER inverters manufactured by respondents.

**Results:** Ten respondents skipped this question. Of those replied, three indicated that the hybrid techniques are not currently utilized, leading to a high percentage of the "Other" category. Out of the remaining four respondents, technique based on positive feedback and voltage unbalance, hybrid Sandia voltage shift and Q-f, hybrid Slip-mode frequency shift and Q-f are the three techniques that are relatively more popular. Technique based on either voltage and reactive power shift, or rate of change of frequency and impedance measurement are also utilized, but with a lower adoption ratio (14.3%). One respondent specified a hybrid method of AFD and ROCOF, which is currently used but not included in the provided list.




| | |
|---|---|
| A | Technique based on positive feedback and voltage unbalance |
| B | Technique based on voltage and reactive power shift |
| C | Technique based on voltage and active power shift |
| D | Technique based on local measurements and high frequency component evaluation |
| E | Hybrid Sandia voltage shift and Q – f islanding technique |
| F | Hybrid Slip-mode frequency shift and Q – f islanding technique |
| G | Combination of Rate of change of frequency and Impedance measurement |

**Figure 3-6**
**Hybrid islanding detection method (7 respondents)**

**Question 7**: **If applicable, what COMPUTATIONAL INTELLIGENCE BASED islanding detection tool(s) (or similar) are available in the DER inverters from your company?**

**Purpose:** Illustrate how widespread each computational intelligence based islanding detection technique is among DER inverters manufactured by respondents.

**Results:** Eleven respondents skipped this question. Of those replied, two indicated that they currently do not have computational intelligence implemented. Out of the remaining four respondents, three employ the artificial neutral network (ANN) based islanding detection scheme, and the other adopts proprietary method that is not included in the provided list.

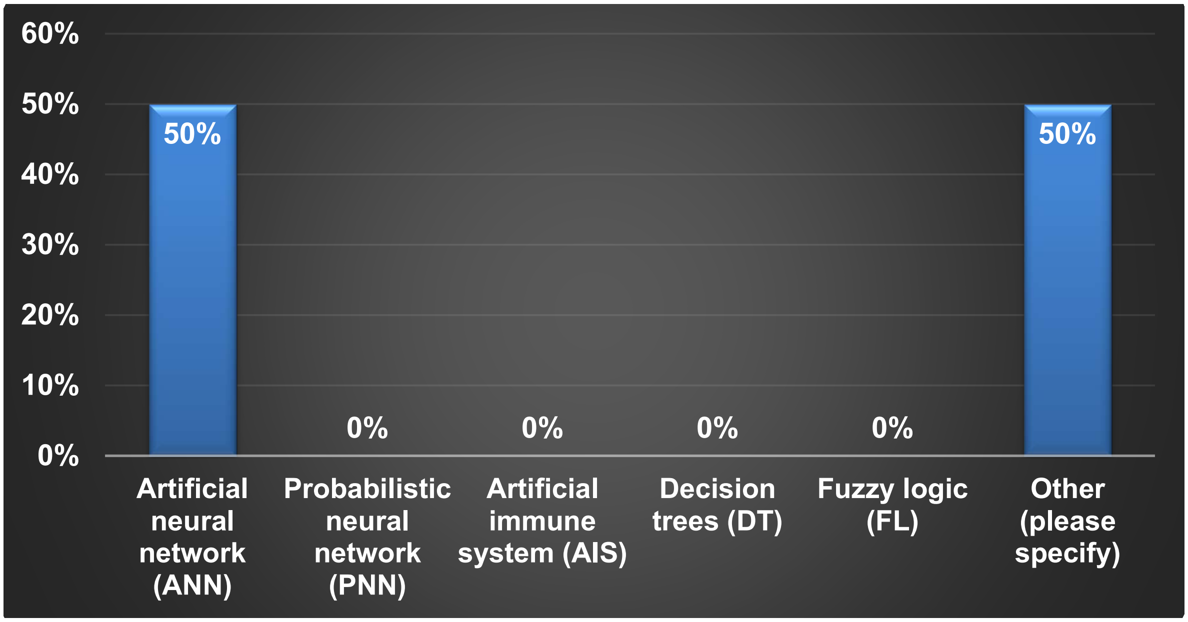



**Figure 3-7**
**Computational intelligence based islanding detection technique (6 respondents)**

**Question 8**: **What is the minimum time in which the DER inverter from your company can detect formation of an unintentional island?**

**Purpose:** Learn the minimum detection time of commercial DER inverters and whether it satisfies the related standards

**Results:** 88.3% of respondents confirmed that with the on-board detection schemes, DER inverters can detect the unintended island within 2s, as required by the IEEE 1547 standard, among which nearly half (47.1%) claimed that their inverters can detect the island within 200 ms. Two respondents provided their concerns on this survey question, as quoted below, which led them into the "Other" Category.

1. Depends upon how well-balanced P and Q are at S3 when opened, worst case typically 700 ms, best case < 1 cycle
2. This is a complex question and depends on many factors of the utility system and neighboring DERs, rotating machinery, loads, etc.

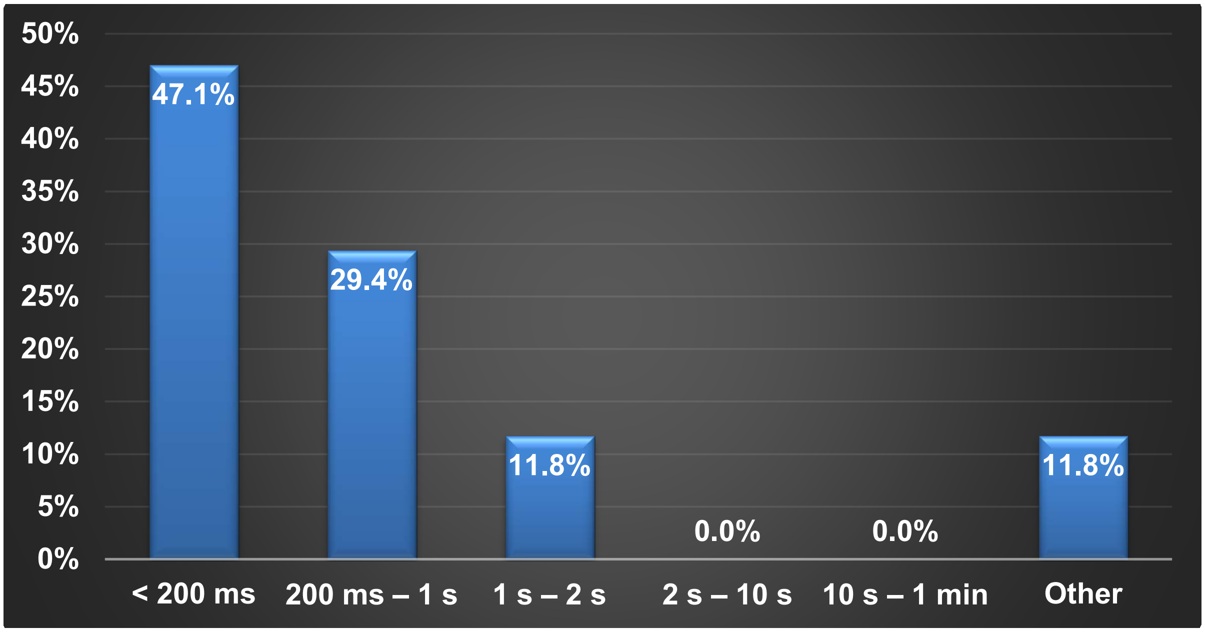



**Figure 3-8**
**Minimum unintentional island detection time (17 respondents)**

**Question 9**: **Do you have any suspicion or evidence of functional conflict between islanding detection and other smart inverter functions?**

**Purpose:** Figure out the manufacturers' experiences on functional conflict between islanding detection and other smart inverter functions

**Results:** Total votes: 17

| Yes | No |
|---|---|
| 82.4 % | 17.6% |

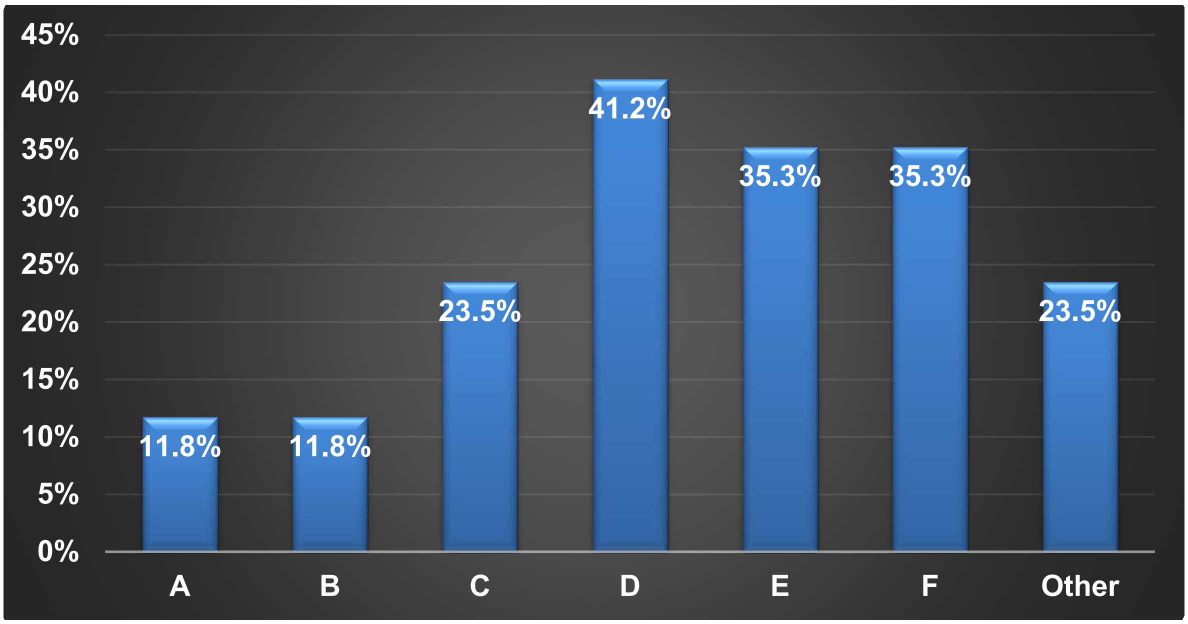
The majority of respondents (82.4%) have not seen any functional conflict between islanding detection and other smart inverter (grid support) functions. Of those answering "Yes," one respondent specified that such concerns applied to Volt/Var (not during steady state but while changing VAR from one value to other value), and the other respondent has concerns that 1) As frequency range get wider, it takes more time for the inverter to trip; 2) Low/high frequency ride through. L/H voltage may also affect.

**Question 10**: **According to you, what should be the future of anti-islanding protection?**

**Purpose:** Figure out what types of anti-islanding protection manufacturers are expecting

**Results:** Communication mechanism, such as Transfer Trip, Power line carrier communication (PLCC), is the most common type of anti-islanding protection, with 41.2% of respondents showing their faiths on it. The second common trend is "Harmonization of methods and/or elimination of ineffective/ incompatible methods", with 35.3% of respondents voted for this. On the other hand, nearly one third of the respondents regarded islanding as a situation that can be utilized, instead of trying to eliminate it. Of those selecting “other”, different perspectives were provided, as quoted below:

1. Large Scale transmission or distribution connected systems should rely on a separate controllable disconnect
2. communication mechanisms with active AI backup




| | |
|---|---|
| A | Simply integrating new grid codes should be sufficient (both from the DSO and TSO perspective) |
| B | New passive islanding detection mechanisms |
| C | Active detection mechanisms |
| D | Communication mechanisms |
| E | Harmonization of methods and/or elimination of ineffective/ incompatible methods |
| F | None, we should learn to control and use islanding situations instead of trying to eliminate them |

**Figure 3-9**
**Expected future anti-islanding protection (17 respondents)**

**Question 11**: **Do you expect to update/modify islanding detection algorithms due to the changes in IEEE 1547 standard?**

**Purpose:** Understand potential impacts of the new IEEE 547 standard and figure out whether manufacturers consider updating islanding detection algorithms accordingly

**Results:** Total votes: 17

| Yes | No |
|---|---|
| 5.9 % | 94.1% |

The majority (94.1%) of respondents do not anticipate changing their existing islanding detection algorithm due to the changes of the IEEE 1547 standard, indicating that they believe the existing detection techniques are sufficiently effective. One respondent selected “Yes”, and specified the considered adaptions as “L/H frequency ride through must be accommodated, eliminating passive anti-island method”.

**Question 12**: **Will you offer more options for anti-islanding protection due to the upcoming IEEE 1547 standard?**

**Purpose:** Understand potential impacts of the new IEEE 547 standard and figure out whether manufacturers consider offering more anti-islanding protection accordingly

**Results:** Total votes: 17

| Yes | No | Have not considered |
|---|---|---|
| 5.9 % | 41.2% | 52.9% |

Similar to the results form Question 11, the majority of the respondents either have not considered (52.9%) or do not anticipate (41.9%) any additional anti-islanding protection schemes, as a response to the new IEEE 1547 standard. One respondent selected “Yes”, and specified the considered adaption as “Communicate via Main Site Controller - require Grid operator to order anti-island”.

## 3.3 Conclusions

This chapter describes the results of DER inverter manufacturer survey, and the key findings are summarized below:

1. Islanding detection methods are mainly implemented in PV and ES inverters, but they are also available in fuel-cell, wind-turbine and future EV to grid inverters.
2. Many detection methods can be indemnified in the literature, however currently passive and active are the main techniques adopted in commercial DER inverter.
3. For passive islanding detection methods, rate of change of frequency, over/under frequency/voltage, voltage unbalance, and phase jump are widely used
4. For active islanding detection methods, techniques that perturb the angle or power output and “push” the frequency out of the normal range are most popular
5. Survey respondents indicated confidence that their inverters detect islands at any conditions within 2s, and 80% of respondents claimed that islands can be detected within 1s.
6. A few respondents indicated they do intend to change islanding detection with the advent of grid support.
7. Communication based anti-islanding techniques are regarded as the most promising anti-islanding protection in future.

# 4
# CONCLUSION AND FUTURE WORK

## 4.1 Conclusions

This report provides results of an in-depth literature review on state-of-the-art islanding detection schemes (IDMs) intended to identify the landscape of possibilities. The report then summarizes results of an inverter manufacturer survey identifying current practices for IDMs adopted in typical real-world DER.

In the literature review, IDMs are categorized into two big groups: inverter on-board techniques and utility level techniques. The inverter on-board techniques can be further classified into four subgroups: passive, active, hybrid and computational intelligence based methods. Passive methods are expected to have fast detection speed with relatively large non-detection-zones (NDZ). Active methods will typically reduce the NDZ by intentionally injecting perturbations, which, however, require longer detection time and may degrade the power quality. Hybrid techniques combine the features of passive and active methods, providing an effective detection with the potential to mitigated power quality degradations. The computation intelligence-based methods have the smallest NDZs, but at the cost of relatively complicated algorithms.

The utility level techniques are often a stop-gap, used when DER penetrations near or exceed minimum loading. These involve utility-controlled actions usually activated when primary protective devices open on a feeder. They are designed to be fast and usually are very effective for individual large systems. Both cost effectiveness and reliability become a challenge with many DER of various sizes and types, as well as trends to more in-line reclosers and reconfiguration options.

The DER inverter manufacturer survey provides a basis for the generic response model development. From the survey, the most popular passive as well as active IDMs were identified. Moreover, the manufacturers' response to the changes of IEEE 1547 standard are learned. In general, most of the respondents have faith in their existing anti-islanding protection techniques, and anticipate neither modifications nor additional options to satisfy the new standard.

## 4.2 Future Work

Leveraging the gathered information in this report, responses of different inverters will be categorized into six "groups", based on which a set of non-proprietary islanding response models with closely matched dynamic and steady state behaviors will be developed. It is expected that the set includes 6-8 different time-domain models in a format such as Matlab, and useable by utilities, consultants, and other stakeholders.

Leveraging the developed response model, risk of unintended island will be evaluated on both the generic and actual feeder models built in Powerfactory software under a wide range of test scenarios, considering an increasing penetration of DER and diverse deployment approaches. Sensitivity study will be conducted to identify and catalog the most relevant circuit conditions, load types, DER penetration level, control function combinations. Further, if possible, mitigation options will be evaluated and prioritized based on cost and effectiveness.

The generic response model as well as identified high-risk conditions will then be tested with both controller and power HIL (C-HIL and P-HIL) platform in AIT and Clemson. This allows the project team to validate the developed response model as well as risk assessment results, using physical controller or inverter hardware.

Based on testing and analysis results, key factors in the risk of unintentional islanding conditions will be identified and utilized to update anti-islanding screening procedures, such as NY Joint Utilities, CA IOUs, and Sandia’s screening procedure, considering the new IEEE 1547. The ultimate objective is to help utilities mitigate the risk of unintended islanding at minimum cost, considering inverters’ on-board detection capabilities as well as feeder and load characteristics of a specific site.

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