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A REVIEW OF ISLANDING DETECTION IN MICROGRIDS

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Abstract: *The increasing integration of Distributed Energy Resources (DER) such as solar photovoltaics, wind turbines, and energy storage systems into modern power systems has led to the rapid evolution of microgrids. Microgrids offer numerous benefits, including improved energy resilience, reduced transmission losses, and the facilitation of renewable energy adoption. One of the critical challenges associated with microgrid operation is the phenomenon of islanding—a condition in which a microgrid or a portion of the power system continues to operate in isolation from the main utility grid after a disturbance, such as a fault or maintenance-induced disconnection. This review paper provides a comprehensive examination of existing islanding detection methods, broadly categorizing them into passive, active, hybrid, and communication-based approaches. We present these methods in terms of detection speed, accuracy, Non-Detection Zones (NDZ), impact on power quality, and compatibility with various DER technologies. By consolidating and evaluating the current landscape of islanding detection strategies, this review aims to guide researchers and system designers in selecting or developing appropriate detection mechanisms for reliable microgrid operation in both grid-connected and islanded modes.*

Key words: Microgrid; Islanding Detection; Distributed Generation; Non-Detection Zones (NDZ); Renewable Energy

1 Introduction

The concept of 'islanding' regarding a microgrid refers to a situation where a microgrid is unknowingly disconnected from the utility grid while still retaining supply from the energy sources within it (Arif et al., 2021). An islanded microgrid contains one or more synchronous generators; a renewable energy source or a DER supplying a localized load or several load buses, as shown by the reference (Samson et al., 2021). The global shift toward renewable and distributed energy resources has introduced new complexities in power system stability (Yi et al., 2019). Among these, islanding of microgrids and Distributed Energy Resources (DERs) is one of the most significant challenges, as it may lead to unsafe operating conditions, equipment damage, and violation of regulatory standards if not detected effectively. Ensuring fast and reliable islanding detection is therefore a key requirement for both utilities and Distributed Generator (DG) owners, according to reference (Bharti et al., 2021). This literature review serves as a critical step in addressing this challenge because it provides a systematic classification of islanding detection methods (passive, active, communication-based, hybrid, and AI-driven approaches), clarifying their underlying principles. A critical evaluation of the strengths, limitations, NDZ characteristics, and detection times of each method under different operating conditions is presented. A highlight of practical challenges and adaptability to high-DG penetration grids is appraised. Moreover, trends and future directions, with particular focus on hybrid detection schemes, data-driven approaches, and integration with wide-area monitoring systems, are considered. Thus, the review offers a reference framework for researchers, utilities, and policymakers to guide the development of more robust, reliable, and standardized anti-islanding solutions.

2 Review of Islanding Detection Methods for Microgrids

The implementation of renewable energy sources has gained a notable place in modern power grids, with wind turbine systems and solar photovoltaic systems leading the way (Jain & Jain, 2017). As shown by the reference (Karthikeyan et al., 2017), a microgrid can be grid-connected or off-grid. The off-grid microgrid, by design, is made to operate by being separate from the utility grid at all times. For grid-connected microgrids, an islanding occurs when a microgrid is separated from the utility grid due to the tripping of its circuit breaker, as shown in Figure 2 and reference (Silvanus D'silva et al., 2020). Tripping of the microgrid breaker can be caused by faults in the utility grid, malfunction of the microgrid's protection device, and failure of the microgrid's control system. It is crucial to note that faults occurring within the microgrid itself, such as short circuits on the generators, lines, transformers, and feeders, do not cause islanding. Instead, these faults are managed by the microgrid's protection systems, which isolate the affected sections to maintain overall system stability (Talapur et al., 2018).

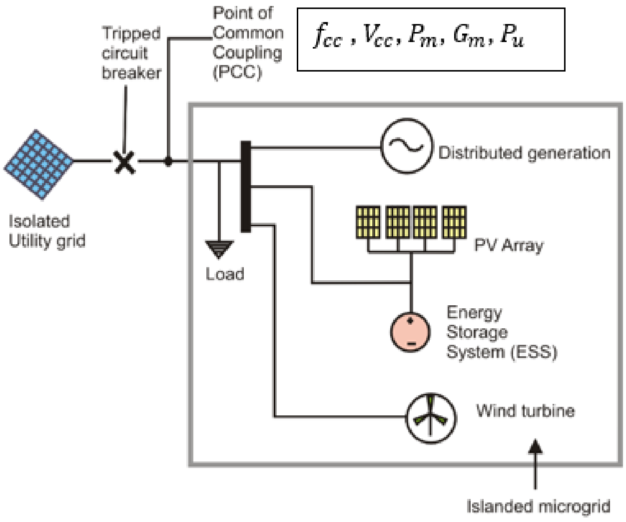

Figure 1: Illustration of an islanded microgrid

where:

f_{pcc} is the measured frequency at the Point of Common Coupling (PCC)

V_{pcc} is the measured Voltage at the PCC

f_{tr} is an established frequency threshold

V_{tr} is an established voltage threshold

G_m is the sum of the installed capacity of the microgrid, i.e., distributed generators, PV arrays, and wind turbines

P_m and Q_m are instantaneous real and reactive power generated from the microgrid.

P_u real power generated from the utility grid

Although the fuel for renewable energy sources tends to replenish itself, their intermittent nature, coupled with the distortions they introduce to the grid, poses problems like undetected islanding, poor power quality, and reactive power management.

In reference (Baum et al., 2006), Islanding poses a hazard for utility personnel because an area of the grid that is considered isolated from the utility grid, while such an area remains energized by renewables and DERs unknown to the utility personnel. This poses a potentially hazardous situation for the utility personnel, as the islanded system remains energized by renewable sources while the utility personnel are unaware of the presence of renewables within the islands. According to the reference (Hoke et al., 2021), the power system variables within an islanded microgrid usually experience a sudden increase or decrease, which leads to loss of voltage regulation and poor frequency control within the islanded microgrid, consequently leading to harmonic distortions at the consumer end. A large departure of voltage from normal operating conditions can cause damage to equipment not suitable for islanding operation. Exceeding high voltage can damage the insulation of power transformers. Low voltage can cause overheating and stalling of electric motors. Low voltage conditions can also put a strain on capacitor banks(Reigh & Don, 2002). The author of reference (Lagos et al., 2021) showed that islanding can also lead to reverse power flow from the DERs and cause the maloperation of relays and false tripping. Equipment not suitable for reverse power flow can be damaged. The presence of reverse power flow in microgrid islands is usually difficult to detect if the resultant power flow appears to be within acceptable operational limits. The sudden disconnection of a microgrid, which forms islands, tends to impact the synchronism of DERs that operate by acquiring a reference from the utility grid. Thus, a sudden disconnection of the DERs from the utility grid can lead to a loss of synchronism and, consequently, a collapse within the microgrid according to the reference (Galina et al., 2012).

The consequences of islanding have been discussed earlier. Suitable methods for detecting islanding in microgrids, renewables, and DERs are essential from the perspective of an electric utility provider.

A Non-Detection Zone (NDZ) is defined as an area within the operational space of a microgrid where islanding detection methods fail to identify an islanding condition. This occurs when the resultant effect of the islanding produces minimal or zero mismatch between the power generated by DERs and the local load, resulting in negligible changes in voltage and frequency at the PCC, as shown by reference (Ye et al., 2004).

The search for the detection of islanding for microgrids has received great attention from researchers (Bakhshi-Jafarabadi et al., 2022). Numerous techniques have been established, which can be broadly grouped into the classical and modern methods as depicted in Figure 2.

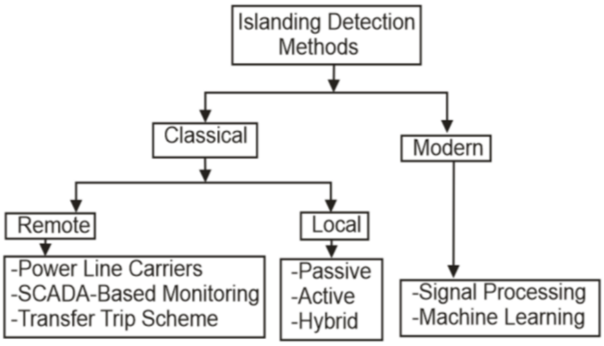

Figure 2: Classification of islanding techniques (Dutta et al., 2018)

2.1 Classical Methods

The classical methods rely directly on easily measurable electrical quantities and compare them to a threshold. Thus, islanding is established when the thresholds are violated. They are considered to be the fundamental and most basic form of islanding detection.

2.1.1 Remote Methods

According to the reference (Mohammadzadeh Niaki & Afsharnia, 2014), remote methods or communication-based methods for detecting islanding entail establishing a communication link within the microgrid or between the microgrid and operators of the utility grid to detect islanding. Remote techniques usually offer a high success rate in detecting islanding and require no additional effect on the power quality. They also offer a zero NDZ and can detect an islanding within a short time. However, they are highly expensive to implement and require complex infrastructure.

With a power line carrier installed between the controllers of a utility grid and the microgrid, a signal is sent from the transmitter (controllers of the utility) to the receiver (controllers of the microgrid). Thus, if the signal fails to reach the microgrid due to its breaker tripping. The controllers of a microgrid see this as an islanding(Scott et al., 2015).

The reference method (Enikő et al., 2015) entails deploying Supervisory Control and Data Acquisition (SCADA) technology to monitor the power system variables around the microgrid. Although effective, it can be cumbersome and quite expensive to implement.

The Transfer Trip Scheme entails a system for ensuring the energy sources in a microgrid are made to shut down once islanding is detected. Although the method provides fast detection of islanding fault, the method is also cost-intensive and entails an elaborate interconnection between the operators of the utility grid and the microgrid (Jun Yin et al., 2004)

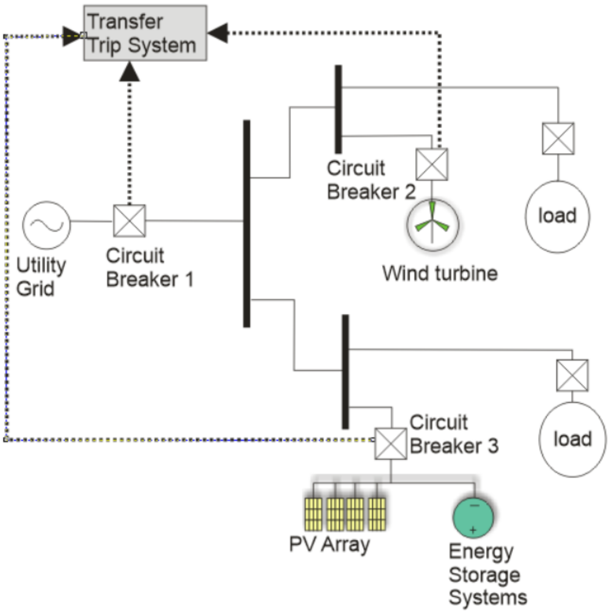

Figure 3: Transfer Trip Scheme (Jun Yin et al., 2004)

The transfer trip scheme is illustrated as follows: If the microgrid is islanded by the tripping of circuit breaker 1, the transfer trip system automatically detects this occurrence and automatically opens circuit breakers 2 & 3. In this way, the wind turbine and PV are separated from their localized load and preventing islanding.

2.1.2 Local Methods

Local methods are implemented by continuously monitoring the conditions of the power system variables from within the microgrid setup and basically entail 3 subclasses: passive methods, active methods, and hybrid methods. They do not have an additional effect on the power quality and cost less to implement. However, determining a reliable threshold to signify an islanding fault requires continuous study of the microgrid. Also, an islanding fault will be difficult to detect for scenarios where there is a close match between the generators in the microgrid and their respective load. The local electrical load within a potential island is typically represented as a parallel RLC circuit. RLC loads with a high value of the quality factor Q are the most challenging to detect using common passive islanding prevention methods. Conversely, nonlinear loads—such as those that produce harmonics or maintain a constant power draw—are generally easier for these methods to identify according to the reference (Wei & Chee, 2011). This consequently causes passive island detection techniques to have a large NDZ, making them prone to error.

It has been established that islanding faults greatly influence the power system variables within a microgrid. Passive methods entail keeping track of the power system variables within the microgrid, after which an islanding fault is detected by comparing these parameters with a predefined threshold value.

The voltage and frequency of DGs and renewables are usually within specified limits when connected to the utility grid. Thus, when the microgrid is islanded, the voltage and frequency as measured at the PCC increase and depart from the specified thresholds as shown by reference (Mahat et al., 2011). Thus, islanding is established when equations (1) & (2) hold.

$$|f_{pcc} - f_{nominal}| > f_{tr} \qquad (1)$$

$$|V_{pcc} - V_{nominal}| > V_{tr} \qquad (2)$$

Where f_{tr} and V_{tr} are frequency and voltage threshold limits obtained through the study of the microgrid.

According to reference (Yang & Chang, 2009), the Rate of Change of Voltage (ROCOV) is based on the observation that, under islanded conditions, the voltage at the point of common coupling (PCC) exhibits sudden and abnormal variations due to the mismatch between generation and load demand. By continuously monitoring the derivative of the PCC voltage with respect to time, the ROCOV index can detect rapid changes that signify the transition into an islanded state. Under normal grid-connected conditions, the system voltage remains relatively stable, and the ROCOV value stays within a narrow range. During islanding, due to load–generation imbalance, the PCC voltage fluctuates significantly, leading to a high ROCOV value that exceeds a preset threshold. Once this threshold is crossed, an islanding event is declared, and the DG unit disconnects from the network. Voltage Ripple-Based Method

The reference (Ansari & Gupta, 2021) proposed a voltage ripple–based technique for islanding detection in photovoltaic inverter systems. The detection process involves a series of differentiation and filtering. First, the voltage (v1) is measured at the PCC. To isolate specific components, $v1$ is passed through a low-pass filter to remove frequency components higher than the nominal frequency, yielding an intermediate signal $v2$. This signal is then differentiated to produce $v3$. The filtering and differentiation process is repeated: $v3$ is filtered to remove high-frequency components to get $v4$, which is then differentiated to obtain $v5$. Finally, $v5$ is filtered to yield v6. If the resulting signal, $v6$, exceeds a predetermined threshold, an islanding event is established.

The voltage unbalanced method relies on the condition that the magnitude of the three-phase voltages is not equal for islanded microgrids, as shown in the literature of reference (Jang & Kim, 2004). This is because an island fault can cause unbalanced voltage at the PCC. This unbalance is measured by calculating the Voltage Unbalance Factor (VUF) (8):

$$VUF = \left|\frac{V^-}{V^+}\right| \times 100\% \qquad (3)$$

where:

V^+ is the positive sequence voltage

V^- is the negative sequence voltage

If the unbalance exceeds a threshold (typically 2–3%), it can indicate a possible islanding situation.

The reference (M. Mishra & Pati, 2022) introduces a straightforward passive islanding detection method that utilizes the voltage unbalance factor (VUF). When the utility grid becomes disconnected, the sequence components exhibit rapid and noticeable fluctuations, which can be effectively detected through changes in the VUF. Accordingly, the rate of change of voltage unbalance (ROCOVU) exceeding a predefined threshold is used to indicate islanding. The proposed technique is validated using a test system comprising a synchronous generator that is mechanically driven by a renewable energy prime mover.

The author of reference (Resende et al., 2022) showed that when a microgrid is connected to the utility grid, the voltage and frequency are tightly synchronized with the grid. In the event of an islanding fault (i.e., the grid disconnects), the microgrid must maintain synchronization on its own with the local load. A mismatch between the microgrid's power output and load can cause a sudden jump or shift in the voltage phase angle at the PCC. This shift can be tracked using a Phase Locked Loop (PLL) between the PCC and the inverter's output.

The author of references (Lingampalli et al., 2023) and (Pinto et al., 2024) establishes an islanding fault based on the differential phase angle of the voltage and current at the DG output to determine the islanding scenario on the principle that a microgrid connected to the stiff utility grid has a stable differential phase angle. Conversely, when the microgrid is isolated, the impedance changes drastically, causing a sudden, measurable shift in the differential phase angle, thereby signalling an islanding fault. The novel passive approach is proven to have a near-zero NDZ and a significantly low detection time.

The novel method, as established by reference (Bashir & Jena, 2023), is a measure of deviation of the DG's respective output voltage and current positive sequence quantities from a predefined threshold. Additionally, the phase angle difference between the positive sequence voltage and current is calculated. Thus, islanding is established using 2 criteria: the first is that the magnitude of positive sequence voltage and current must exceed a predefined threshold. Second is that the phase angle difference between the positive sequence voltage and current must be negative.

The reference (Srikanth Goud et al., 2023) introduces a new islanding detection technique for DGs based on the Rate of Change of Phase Angle Between Positive Sequence Voltage and Current (RCPABPSVAC). The method identifies an islanding event when the phase angle between the DG terminal's positive sequence voltage and current surpasses a set threshold. This scheme has demonstrated high effectiveness, particularly in scenarios with nearly zero power mismatch.

Without the aid of any sensor for voltage estimation, the reference (Liserre et al., 2006) reconstructed the grid voltage using voltage measurements at the PCC by using a Kalman filter. The algorithm establishes islanding by comparing the energy mismatch between the reconstructed and measured higher-order voltage harmonics in the error signal. The scheme was able to detect islanding under real and reactive power mismatch conditions. In addition, the scheme showed an improved NDZ compared to other pass methods.

The author of reference (Parol & Połecki, 2020) showed that for microgrids connected to the utility grid, the Rate of Change of Output Power (ROCOP) of the microgrid would be in response to changes in load as described in equation (3):

$$\Delta P_m = \frac{G_m H_m}{G_m H_m + G_u H_u} \Delta P_l \tag{4}$$

where H_m *and* H_u are inertia constraints of the microgrid and utility grid, respectively. ΔP_m is usually less than ΔP_l when the microgrid is connected to the utility grid. A disconnection of the microgrid from the utility grid sets $G_u H_u$ to zero thus $\Delta P_m = \Delta P_l$. Because $G_u > G_m$, the rate of change of power output from the microgrid ${}^{\Delta P_m}/_{\Delta t}$ becomes much greater. This method is only effective if the microgrid is running far below its maximum output power. Thus, if islanding of the microgrid occurs, $\Delta P_m = 0$, hence ${}^{\Delta P_m}/_{\Delta t} = 0$, which fails to indicate islanding. On the other hand, the reference (Nikolovski et al., 2019) proposes a highly effective passive islanding detection method specifically tailored for large power synchronous generator-based DGs, such as those found in biomass power plants. When a synchronous generator-based DG is disconnected from the stiff utility grid (islanding), the sudden loss of the grid's reactive power support causes a distinct and measurable transient in the local system's reactive power, resulting in a large, immediate spike in the value. The study demonstrates that this immediate spike in reactive power is a reliable yardstick for detecting the islanded operation mode for large synchronous generator-based DGs.

The author of reference (Gupta et al., 2017) showed that for every load change within the microgrid, the frequency measurements obtained at the PCC change with time based on the established equation (4):

$$\frac{\Delta f}{\Delta t}_{normal} = \frac{\Delta P f}{2(H_m + H_u)(G_m + G_u)} f \tag{5}$$

When islanding of the microgrid occurs H_u and G_u become zero transforms equation (4) to equation (5):

$$\frac{\Delta f}{\Delta t}_{islanded} = \frac{\Delta P f}{2 H_m G_m} f \tag{6}$$

Thus, by measuring the Rate of Change of Frequency (ROCOF), islanding of the microgrid is established when the calculated ROCOF exceeds the normal ROCOF according to equation (6):

$$\frac{\Delta f}{\Delta t}_{calculated} > \frac{\Delta f}{\Delta t}_{normal} \tag{7}$$

Moreover, the author of reference (Altaf et al., 2022) provided an adaptive ROCOF method that uses the microgrid's own PLL settings to dynamically set the necessary ROCOF threshold, thereby achieving reliable islanding detection and discrimination, especially in the problematic zero-power-mismatch scenario. The technique was tested and verified using various microgrid configurations.

The reference method (Prince et al., 2021) established that inverter-based renewables tend to induce distortions in the voltage and currents they produce, particularly when islanded. Thus, the Total Harmonic Distortion (THD) exceeding a threshold is used to indicate the occurrence of microgrid islanding according to equation (7)

$$THD = \frac{\sqrt{\sum_{h=2}^{\bar{h}} I_{l,h}^2}}{I_{l,1}} \times 100 \qquad (8)$$

where $I_{l,1}$ represents the Root Mean Square (RMS) value of the fundamental component of the load current I_l , $I_{l,1}$ $\{h \in \{2, \cdot\cdot\cdot, \bar{h}\}$ is the RMS value of the harmonic component h, and $\bar{h}$ represents the maximum number of harmonic components. Islanding is established when the THD exceeds a threshold THD_{tr}, obtained via extensive study of the microgrid.

On the other hand, the author of reference (Merino et al., 2015) established an islanding fault by monitoring naturally occurring 5th harmonic voltage at the PCC. The reference established that DERs inherently contain ambient harmonics (1–3%), mainly from nonlinear loads and inverter-based devices, after which it was observed that a grid disconnection causes identifiable changes in the 5th harmonic content between grid-connected and islanded modes. The method proved effective for the detection of islanding fault, provided that the islanding fault can cause an increase in the 5th harmonic voltage threshold by approximately 3%. On the other hand, the author of reference (Haider et al., 2019) used reactive power loss and harmonic dominance attributed to an islanded inverter-based DG as indicators for islanding. A harmonic index is formulated from the harmonics extracted from the DG's current and voltage. This index is then compared to a predefined threshold for islanding fault detection. The Discrete Kalman Filter (DKF) is used to extract the desired harmonic components from the measured voltage and current signals. The scheme was proven to be effective with zero active power mismatch conditions.

The author of reference (Kulkarni & Khedkar, 2021) showed that the impedance at the PCC for a grid-connected microgrid is usually low. However, after disconnection, the impedance at the PCC increases. This change in impedance can be used to indicate possible islanding. It should be noted that this method is only reliable for microgrids with small generator units, as larger units are accompanied by a smaller impedance similar to that of the utility grid.

The author of reference (Chaulagain et al., 2025) proposed a new islanding detection method for microgrids based on the Rate of Change of Negative Sequence Impedance Angle (ROCONSIA) using measurements from Distribution Phasor Measurement Units (D-PMUs) to achieve fast, accurate, and robust detection with a negligible non-detection zone (NDZ). On the other hand, the author of reference (Pachauri & Chandel, 2025) also implemented (ROCONSIA), however, with measurements at the PCC.

The Rate of Change of Superimposed Impedance (ROCSI) established in the reference (Tadikonda et al., 2022) is designed to quickly and reliably distinguish islanding from other disturbances in a microgrid. When an abnormal event (like islanding, a fault, or load switching) occurs, it introduces transient changes in the system's voltage and current. The method extracts the superimposed components of the voltage and current, which represent the change in the signal before and after the disturbance. The superimposed impedance is calculated as the ratio of the superimposed voltage and current components. When the microgrid disconnects from the strong utility grid, the system impedance seen by the DG abruptly changes from the very low impedance of the utility grid to the much higher, local load impedance. This dramatic and sudden change causes the ROCSI to experience a very large spike. For non-islanded cases during internal faults, load switching, or other normal transients, the grid remains connected. Although the superimposed impedance changes, the presence of the strong grid connection dampens the transient, resulting in a significantly smaller and less sustained change in the ROCSI. A comparison of some passive methods is shown in Table 1.

Table 1: A comparison of some passive methods for island detection

Method	Principle	Advantages	Disadvantages	NDZ Size	Typical Detection Time
Under/Over Voltage (UV/OV)	Monitors bus voltage magnitude; trips if outside preset thresholds	Simple, low cost, easy implementation	Large NDZ when load matches generation; poor sensitivity near nominal voltage	Large (especially at unity power factor, high-Q loads)	100–300 ms
Under/Over Frequency (UF/OF)	Detects frequency deviation due to the imbalance of generation and load	Simple, widely used, effective under large mismatches	Large NDZ when generation closely matches load; insensitive to frequency-regulated DG	Large	100–300 ms

Rate of Change of Frequency (ROCOF)	Trips if ROCOF exceeds a threshold	Faster detection than UF/OF; sensitive to small imbalances	May nuisance trip under normal disturbances (e.g., load switching); poor with high inertia systems	Medium to Large (depends on settings)	100–200 ms
Rate of Change of Voltage (ROCOF)	Detects voltage transients or drifts	Sensitive to load-generation mismatch	False trips under voltage fluctuations; ineffective near-perfect match	Medium–Large	50–150 ms
Voltage Phase Jump Detection	Detects sudden phase angle shift at PCC during islanding	Can detect certain RLC load mismatches	Sensitive to measurement noise; may fail with slow drifts or high-Q loads	Medium	50–150 ms
Harmonic Detection	Monitors harmonic distortion levels at PCC	Effective where nonlinear loads are present	Poor with linear loads; harmonics may not always indicate islanding	Variable (depends on load type)	100–250 ms
Voltage Unbalance	Detects imbalance or distortion in three-phase voltage	Useful in unbalanced or distorted systems	False alarms possible; limited use in balanced, clean systems	Medium	100–200 ms

This active method entails carrying out perturbation studies on the microgrid by creating perturbations or disturbances on the power system variables of the microgrid while it is disconnected from the utility grid to ascertain the dynamics of the microgrid when isolated from the utility grid. They generally have lower NDZ and are far less prone to errors in comparison to the passive methods. However, the associated perturbations can enlarge over time and contribute to the instability of the utility. Also associated with this method is implementation cost and complexities (Panigrahi et al., 2021).

This is an active islanding detection technique used primarily in microgrids dominated by grid-following inverter-based resources, as illustrated by the author of reference (Sanchis et al., 2005). This method is implemented by slightly altering the inverter output in terms of phase angle or frequency and observing the system's response. If the microgrid is connected to the utility grid, the grid acts as a voltage stiff source, thereby dampening the shift. However, if the microgrid is disconnected from the utility grid and there is no Battery Energy Storage System (BESS) to provide a voltage reference, the power system within the microgrid drifts freely, as there is no reference for the grid-following inverters. This drift in operation can be used to indicate an islanding fault. However, this method is unsuitable for later inverters, which are grid-forming inverter-based microgrids their reference signal is not obtained from the utility grid. There are variations to this approach. It should be noted that each variation aims at the same end: to use the impact of frequency perturbations in the output of a grid-following dominated microgrid as a means to detect islanding.

The author of reference (Lopes & Zhang, 2008) showed that the active frequency drift method is implemented by modifying the inverter's output current waveform through the introduction of small, periodic disturbances. The rate of frequency change is then monitored. Thus, a significant deviation above a threshold indicates potential islanding. Although simple to implement and effective in many scenarios. It tends to have a large NDZ when the local load perfectly matches the inverter's output power. However, the author of reference (Dmitruk & Sikorski, 2022) improved on the challenge of AFD having a large NDZ when the inverter's output power matches its local load perfectly by introducing a periodic current disturbance signal into the output current of the inverter that is synchronized with the voltage zero-crossing time. In grid-connected mode, the injected disturbance has minimal effect on the grid frequency and voltage. When the grid connection is lost, the disturbance forces the local frequency to quickly drift outside of the permissible operating range, triggering a fast trip. Consequently, the study confirms that the improved AFD method successfully eliminates the NDZ challenge under balanced load conditions. On the other hand, the reference (Murugesan & Murali, 2019) created perturbations in DG's output by injecting a small periodic current via the DG's q-axis current controller. The instantaneous frequency, extracted from the three-phase voltage, is processed through a band-pass filter, and the mean of Absolute Frequency Variation (AFV) is calculated. A trip signal is generated if the mean AFV exceeds a predetermined threshold. This novel method also offers fast detection time and zero NDZ.

The reference method (Ghardashi et al., 2022) establishes a positive feedback loop between the microgrid's frequency and the DG's injected reactive power. The microgrid is perturbed by slightly altering a DG's reactive power output based on a function of the measured system frequency. When connected to the stiff utility grid, the grid's large inertia and stable frequency reference absorb the small reactive power perturbation. The frequency remains largely unaffected, and the feedback loop is suppressed. However, when the grid is lost, the isolated microgrid's small, local impedance takes over. The same reactive power perturbation now has a direct and amplified impact on the system frequency. The positive feedback loop accelerates this frequency change, quickly pushing the frequency outside its normal operating band. Islanding is confirmed when the frequency is driven past a defined threshold. The method is well-suited for inverter-based sources like PV systems.

According to the author of reference (Shahrokh et al., 2016), a drift in the frequency is achieved by applying positive feedback to the inverter's current phase angle. This method is deemed faster for the detection of islanding compared to AFD. However, it requires precise control to avoid instability. The studies of the reference(Zhu et al., 2025) further revealed how droop-based Grid-Forming (GFM) inverters impact Slip-Mode Frequency Shift (SMS) islanding detection. A small-signal model showed that SMS and Q–V droop coefficients are key to balancing stable grid operation and effective islanding detection.

Developed by Sandia National Laboratories, the Sandia Frequency Shift (SFS) method modifies the output current of the inverter as implemented in the active frequency drift approach, as shown by the author of reference (Zeineldin & Kennedy, 2009). However, the frequency drift is much faster as the SFS method further introduces positive feedback to the output of the inverter. This method can introduce harmonics and therefore requires careful tuning to balance detection speed and power quality. As illustrated by the author of reference (Vazquez et al., 2020), the Sandia Voltage Shift (SVS) method employs a positive feedback loop related to the voltage at the PCC between the inverter and the grid. No external injection is performed. However, the slight variation or distortion is introduced by the inverter into its output current, which in turn influences the voltage. When connected to the grid, the strong grid largely absorbs these small perturbations, and the voltage at the PCC remains relatively stable. The grid's impedance is low, so the slight variations or distortions from the inverter's current don't cause a significant voltage shift. If the grid disconnects, the inverter is now only supplying the local loads. The impedance of these local loads is typically much higher than the grid. Therefore, the small current perturbation injected by the SVS method will cause a much more significant and rapid shift in the voltage at the PCC. It is effective at detecting islanding even when there's a close match between DG supply and local load consumption (which is a challenge for passive methods). In essence, the Sandia Voltage Shift method actively "tests" the grid's presence by introducing a minor voltage perturbation and observing if the grid's strong nature dampens that perturbation. If it doesn't, it's a clear sign of islanding.

The author of reference (Dutta et al., 2018) showed that the voltage and reactive power shift method detects islanding of a microgrid dominated with grid-following inverters by monitoring abnormal patterns in reactive power flow between the microgrid and the utility grid. For a microgrid connected to the utility grid, the effect of increasing the reactive power output of the microgrid does not cause voltage fluctuation because the voltage at the PCC is regulated by the utility grid. However, significantly increasing the reactive power output of the microgrid dominated with grid-following inverter technology causes fluctuations in voltage as the microgrid no longer has a reference from the utility grid, nor is the utility grid available to absorb any excess power from the microgrid. Although no signal injection is needed, coupled with the fact that the method offers low NDZ, the method becomes unreliable if the load closely matches the output of the microgrid. It is also deemed slower in detecting islanding as compared to other methods. Thus, when the microgrid is in islanded mode, increasing its generation leads to a rise in frequency and voltage, while reducing the microgrid's output in islanded mode reduces the microgrid's frequency and voltage

According to the authors of references (Bower & Michael, 2002) and (Trujillo et al., 2010), the frequency jump method is similar to the active frequency drift method. However, the perturbation introduced at the inverters' output is not periodic, but is done for only one cycle. This method is therefore deemed less reliable because it offers a lower error detection rate, particularly in scenarios where the microgrid's load demand matches the inverter's output. On the other hand, reference(Sonam et al., 2019) extended the frequency jump method effectively to a DC grid inverter.

The novelty in reference (Blanco et al., 2022) lies in solving the core conflict of active methods: eliminating NDZ without degrading power quality during normal operation. This is achieved by having every DG simultaneously inject a unique, high-frequency pilot current signal. When the system is grid-connected, the utility grid's very low impedance absorbs these signals, causing them to cancel each other out on the local DC bus. This results in a near-zero voltage ripple, preserving the DC voltage quality. Conversely, when the microgrid islands, the low-impedance path disappears, the local load impedance takes over, and the cancellation mechanism fails. This instantly leads to a large, measurable high-frequency voltage ripple on the DC bus, which serves as a definitive, high-speed indicator of islanding. This distributed, communication-less approach ensures a fast trip decision and a near-zero NDZ while effectively mitigating the power quality issues common to traditional active injection methods.

Like its passive counterpart, this active impedance-based method leverages the fundamental principle that the impedance seen by a DG at the PCC changes drastically when the main utility grid disconnects, according to reference (Mohamad & Mohamed, 2018). When the DG (e.g., a solar inverter) is connected to the strong utility grid, the grid presents a very low impedance. Any small perturbation ΔI injected by the inverter into its output current will result in only a very small, almost negligible, change in voltage at the PCC because the grid acts as a stiff voltage source. When the grid disconnects, the inverter is suddenly feeding only the local loads. The impedance of these local loads is typically much higher than the grid impedance. Therefore, the same small perturbation injected by the inverter will cause a much more significant and detectable change in the PCC voltage. Following the current perturbation at the inverter output, the apparent impedance seen by the inverter at the PCC is calculated according to equation (9):

$$Z_{pcc} = \frac{\Delta V_{pcc}}{\Delta I} \qquad (9)$$

Thus if $Z_{pcc} > Z_{threshold}$ hold, an islanding fault may have occurred.

Harmonic injection–based islanding detection works by deliberately injecting a small pulsating high-frequency harmonic (typically a low-order component such as 3rd, 5th, or 7th) from the inverter into the PCC, as shown by the author of reference (Reigosa et al., 2012). While the system is grid-connected, the grid presents a low impedance at harmonic frequencies, so the injected current produces only a negligible harmonic voltage at the PCC. During islanding, however, the grid is disconnected, the effective impedance rises, and the injected harmonic creates a measurable increase in PCC harmonic voltage. On the other hand, the author of reference (Hasanisadi et al., 2023) proffered a fast active islanding detection method that is proposed by injecting a 4th harmonic into the PV inverter PLL and monitoring PCC harmonics using a modified Goertzel filter. The approach is robust to load variations, detects within two cycles, and achieves zero NDZ with minimal impact on power quality.

The negative-sequence injection method, according to the author of the reference (H. Karimi et al., 2008), relies on deliberately injecting a small negative-sequence current component (unbalanced current) from the inverter into the grid. When the grid is connected, the strong grid source suppresses the effect of this injected current, and the resulting negative-sequence voltage at the PCC remains very small. During islanding, however, the grid is absent, and the PCC is supported only by local loads. This results in a larger negative-sequence voltage response, which can be detected. Let the injected current be described by the equation (10):

$$\mathrm{I}_2 = I_2 \angle \theta \qquad (10)$$

where I_2 is the negative-sequence current phasor, and I_2 is its magnitude.

The Negative-sequence voltage at PCC is described by equation (11)

$$\mathrm{V}_2 = Z_2 \cdot \mathrm{I}_2 \qquad (11)$$

where Z_2 is the equivalent negative-sequence impedance.

When the microgrid is grid-connected, Z_2 is very small due to the stiff grid. Hence $V_2 \approx 0$.

When the microgrid is islanded: Z_2 increases significantly (dominated by load imbalance), leading to V_2 rising above a threshold. Thus, islanding is established if the equation (12) holds.

$$|V_2| > V_{2,\mathrm{th}} \qquad (12)$$

where $V_{2,\mathrm{th}}$ is a predefined threshold.

A new method for active islanding detection in power distribution networks with multiple Inverter-Based Resources (IBRs) was established by the author of (Piaquadio et al., 2025). This method addresses the challenges of existing active islanding detection schemes, such as interference between multiple IBRs and destabilizing the grid during detection. The scheme uses Pulse Compression Probing (PCP) to measure the network's pulse response as seen from an IBR's terminals. This measurement is then used to construct a system model and calculate the nu-gap metric to determine if islanding has occurred. The author stated that islanded conditions cause a large shift in the nu-gap compared to grid-connected operation or non-islanding events (like load or generation changes). The scheme works well with multiple IBRs simultaneously without requiring communication or coordination between them, overcoming a major limitation of other methods.

The reference (A. Kumar et al., 2021) injects a low-frequency sinusoidal current disturbance into the q-axis inner current control loop of the DG's current controller. The reference indicated that the choice of the q-axis over the d-axis is due to its very low impact on THD on generated power. For grid-connected mode, this low-frequency current disturbance flows into the utility grid, which is a low-impedance path, making the disturbance less dominant in the frequency signal at the PCC. However, in islanded mode, the grid is disconnected, and the low-frequency component becomes dominantly present in the PCC frequency, as it now flows into the local load. The Estimation of Signal Parameter via Rotational Invariance Technique (ESPRIT) algorithm is used to extract the modes of oscillation from the frequency deviation signal measured at the PCC. Thus, islanding is confirmed if the dominant frequency modes extracted by ESPRIT are close to the intentionally injected low frequency.

The core idea established by the reference (Huang et al., 2021) is to introduce a controlled, small oscillation into a Direct Current (DC) microgrid's voltage that only grows large enough for detection when an islanding event occurs, thereby improving both detection accuracy and power quality. This frequency is chosen to be within the sensitive frequency band of the islanding system but outside the normal operating frequency range. A small-amplitude signal at this selected frequency is superimposed onto the DG's control voltage. When the microgrid is connected to the strong utility grid, the grid stiffly suppresses the small injected oscillation, and the PCC voltage remains stable and near normal DC voltage. A comparison of the active method is shown in Table 2.

***Table 2:** A comparison of some active methods for island detection*

Method	Principle	Advantages	Disadvantages	NDZ Size	Typical Detection Time
Sandia Frequency Shift (SFS)	Introduces positive feedback into inverter frequency control to destabilize island operation	Very reliable; significantly reduces NDZ	May affect stability and power quality if perturbations are too aggressive	Very Small	100–300 ms
Active Frequency Drift (AFD)	Injects a small asymmetric distortion into the inverter output current	Simple implementation; reduces NDZ	Causes waveform distortion and harmonics; residual NDZ possible	Small	100–300 ms
Slip-Mode Frequency Shift (SMS)	Uses phase angle feedback with frequency error	Very effective at forcing frequency deviation	Can destabilize weak grids; requires precise tuning	Very Small	100–250 ms
Sandia Voltage Shift (SVS)	Perturb the inverter voltage magnitude to reveal the island condition	Simple to integrate into DG control systems	Causes voltage fluctuations; may degrade power quality	Small	100–300 ms
Phase/Frequency Shift Method	Applies deliberate phase or frequency shifts in the inverter output	Robust; can nearly eliminate NDZ	May introduce oscillations; sensitive to parameter settings	Very Small	100–250 ms
Power Shift Method	Alters active or reactive power reference slightly to cause an imbalance	Simple control-based approach; effective detection	Reduces operating efficiency; may affect power quality	Small	100–250 ms
Frequency Jump Method (FJM)	Forces a sudden jump in inverter output frequency and monitors PCC response	Very fast detection; reliable across different loads	May impact sensitive loads; requires precise jump size to avoid nuisance trips	Very Small	50–150 ms
Impedance Measurement	Injects test signals and measures PCC impedance response	Accurate; works for many load conditions	Needs extra measurement hardware; intrusive for sensitive systems	Very Small	50–200 ms
Harmonic Injection / Monitoring	Injects small harmonic signals and observes PCC voltage	Effective with nonlinear loads; reduces NDZ	Increases THD; less effective in grids with very low distortion	Small	100–250 ms
Negative-Sequence Injection	Injects an unbalanced current to detect islanding	Detects islands under balanced load conditions	Creates voltage unbalance and losses; unsuitable for sensitive networks	Small	50–150 ms

The Hybrid methods entail adopting more than one class of islanding detection techniques. Hybrid islanding detection methods, whether combining Active/Passive or Active/Communication, represent the most reliable solutions for modern DG. They successfully address the fundamental trade-off between the large NDZ of passive techniques and the power quality degradation of pure active methods, or the single point of failure and cost of pure communication methods. By strategically combining these approaches, grid operators achieve fast, reliable, and comprehensive anti-islanding protection across all operational scenarios.

Firstly, the passive method is implemented to detect an islanding fault. The passive method strongly suggests islanding has occurred; the active method is implemented to further ascertain situation awareness. This is advantageous as the results of the passive method can help reduce the risk of implementing the active approach, which introduces perturbations to the grid that can cause instability issues, along with deterioration of power quality if not controlled properly. Thus, by reducing the risk of introducing unnecessary perturbations and disturbances, they are more reliable than the active and passive approaches. The author of reference (Mahat et al., 2009) showed that if islanding is suspected using the average ROCOV, the power shift method can be deployed further to effectively assess if an islanding fault has occurred. The reference (Seyedi et al., 2019) proffered a two-stage method that integrates passive and active islanding detection techniques for inverter-based DG units. This mixture utilizes the passive voltage unbalance method and a modified voltage phase jump method. When the voltage unbalance method establishes possible islanding, the phase jump between the PCC and inverters is used to generate a signal noise to the inverter-based DG control block. This noise causes significant changes in the voltage and frequency if true islanding has occurred, leading to fast detection. The technique proposed by the reference (X. Chen et al., 2019)continuously injects a small, varying reactive power disturbance using a linear control strategy into the outputs of all the DGs. Since all DGs observe the same frequency variations, they automatically inject a synchronized reactive power disturbance without needing a high-bandwidth communication link during which the system's frequency and ROCOF are monitored. The scheme entails 2 stages of islanding detection. Firstly, ROCOF and frequency thresholds are used to ensure fast tripping for large power imbalances. If the passive criteria are not met, the injected reactive power disturbance forces a significant frequency change when the DGs are islanded. The detection is then confirmed when the frequency crosses the threshold. This approach minimizes the reactive power injection during normal, grid-connected operation, leading to better power quality compared to fixed-signal active methods.

The hybrid method, as established by the reference (Rajesh Reddy & Pandian, 2019), entails a ROCOF and a reactive power injection method with positive feedback. When islanding is suspected from the ROCOF method, the DG unit deliberately injects a small amount of reactive power into the system. This reactive power injection is given positive feedback. If the system is still connected to the strong utility grid, the small injected reactive power is absorbed, and the system frequency remains stable. However, if islanding has occurred (where the power mismatch is near zero, causing the NDZ), the positive feedback destabilizes the frequency of the isolated microgrid. This instability causes the frequency to quickly move outside the NDZ. The methodology in reference (Fathi-Jowzdani et al., 2022) combines a two-stage approach to achieve robust and reliable detection for DC microgrids. The first stage acts as a high-speed detector for any abnormal change in the system. The system uses a novel metric called the Superimposed Voltage-based Episode of Care Severity Index (SVECS), which quantifies the severity of a voltage change by analysing the transient component of the voltage signal. If the value of this index exceeds a calculated threshold, a significant disturbance is confirmed, and the system proceeds to the second stage, where a superimposed voltage-based current perturbation is injected into the system via the DG. If the main utility grid is still connected, the strong grid will absorb the small injected perturbation, and the measured voltage or current at the PCC will show little to no change. In reference (Bakhshi-Jafarabadi & Popov, 2021), a suspicious islanding condition is detected when the absolute voltage deviation at the PCC goes below a predefined threshold. After a short intentional delay, a transient negative disturbance is injected into the d -axis reference current of the inverter's current control loop. This causes a temporary reduction in the inverter's active power output. In the grid-connected mode, the PCC voltage is maintained by the utility, so the brief drop in the inverter's output causes an insignificant change in voltage. In the islanded mode, a reduction in the inverter's output results in a corresponding voltage drop at the PCC. Therefore, the simultaneous decrease in the inverter's output and the measured voltage at the PCC indicates an islanding event. The algorithm requires only local voltage and current measurements, making it cost-effective and easily deployable for photovoltaic-based microgrids.

In the reference (Serrano-Fontova & Bakhshi-Jafarabadi, 2022), the mini hydro-based microgrid passively monitors ROCOF, which serves as a sensitive initial trip signal. If the measured ROCOF exceeds a defined threshold, indicating a significant power imbalance or disturbance, the system is immediately triggered to proceed to the verification stage, where the power reference of the mini-hydro unit is momentarily modified. This controlled perturbation directly affects the hydro-turbine governor's control system, which, in turn, attempts to adjust the mechanical power output. If the microgrid is grid-connected, the utility grid's high inertia absorbs this change, resulting in a negligible change in the measured system frequency. Conversely, if the microgrid is islanded, the low inertia of the isolated microgrid cannot absorb the change, and the hydro-unit's power modification causes a large, measurable deviation in the system's frequency. This frequency deviation is monitored against a second threshold; if exceeded, the islanding event is confirmed.

Multiple passive methods work on the idea that no single parameter can reliably capture all islanding scenarios. By combining parameters such as frequency, voltage, harmonics, and unbalance, the probability of simultaneously remaining within acceptable thresholds during islanding is significantly reduced. Islanding is declared if one or both indices exceed preset limits. The author of reference (Jhuma et al., 2022) proposed islanding detection by comparing the rate of change of active power and the rate of change of reactive power to predetermined thresholds. The author of reference (Seyedi et al., 2021) deployed the rate of change of active power for island detection only after the ROCOV threshold conditions were met. The reference (Reddy & Reddy, 2019) showed that the ratio of the rate of change of exciter voltage to the rate of change of reactive power for synchronous generator-based DGs is a valid indicator for islanding fault detection. The author of reference (Xie et al., 2020) proposed a new passive islanding detection method for microgrids that considers the dynamic behaviour of loads, unlike traditional approaches that focus only on steady-state RLC load models. The method employs the derivative of the equivalent impedance as seen by a synchronous DG with respect to time as the Islanding Detection Index (IDI). Under islanding conditions, this index approaches zero, whereas it remains nonzero in grid-connected conditions, allowing reliable discrimination. The method is implemented on the basis that ROCOF conditions for possible islanding are established. A key novelty is the incorporation of load dynamics—where active power depends on both voltage and frequency—into the detection process, along with a systematic approach for setting detection thresholds. The Rate of Change of Frequency (ROCOF) + Rate of Change of Voltage (ROCOV) method is a combination that captures dynamic system behaviour. ROCOF indicates real power imbalance, while ROCOV reflects reactive power mismatch. Together, they reduce NDZ and provide faster detection than static methods, although they may be sensitive to short transients. Harmonic Distortion + Voltage Unbalance Factor (VUF) combination relies on the premise that islanding introduces a change in system impedance, often accompanied by increased harmonic distortion and voltage unbalance. This dual approach improves selectivity in systems with nonlinear or unbalanced loads, though it requires high-quality monitoring equipment. The combination of Impedance Variation + Phase Angle Jump is effective for weakly meshed networks but may be affected by noise in practical measurements. On the other hand, a hybrid islanding detection method is proposed by combining Empirical Mode Decomposition (EMD) and Multi-Scale Mathematical Morphology (MSMM), as shown by the author of reference (Nayak et al., 2020). The reference establishes that EMD extracts intrinsic mode functions carrying transient features from targeted DG voltage and current. The approach compares relevant intrinsic mode functions to a predetermined threshold as a means of establishing an islanding fault. The method is proven to reduce detection time and improve accuracy. The author of reference (Swarnkar et al., 2021) proposes a highly effective passive islanding detection scheme designed to work reliably in complex, noisy utility grids with high renewable energy penetration. The core of the proposed method is a specialized decision variable called the Current Islanding Detection Indicator (CIDI), which is a comprehensive metric designed to combine information from current signals, negative sequence current, negative sequence voltage and numerous advanced signal processing techniques to minimize the Non-Detection Zone (NDZ) and discriminate between islanding and other non-islanding events (faults, load changes). The author of reference (Abyaz et al., 2019) established a hybrid passive method combining UF/OF, ROCOF, ROCPAD, and ROCOV relays, achieving fast detection time even at zero DG power mismatch, while eliminating NDZ and avoiding false trips in non-islanding events. The reference (Paiva et al., 2020) proffered a new Wavelet-Based Hybrid Islanding Detection Scheme (WB-HIDS) that uses a modified, real-time implementation of the Continuous Wavelet Transform (CWT) on multiple PCC measurements for passive islanding detection. A proposed active method is triggered only if the established passive detection method identifies a potential abnormality. The novel technique established by the reference (Xie et al., 2021) monitors the Rate of Change of Power Factor Angle (RCPFA) at the DG's terminal. The reference mathematically demonstrates that the RCPFA index approaches zero during an islanding event. In contrast, the index remains high during non-islanding events like faults or switching transients. This distinct behaviour allows the method to better distinguish islanding from disturbances. Furthermore, the reference establishes an adaptively changing threshold to enhance reliability and accuracy. The overall algorithm is activated when the Rate of Change of Frequency (ROCOF) exceeds a small startup threshold, and islanding is confirmed when the calculated RCPFA falls below an adaptively computed threshold. The reference proposed ROCOP-TV, designed for microgrids connected to a Photovoltaic (PV) system. The technique uses a two-step decision process based on local measurements taken at the Point of Common Coupling (PCC). The system first calculates the value of the ROCOP. If the ROCOP value exceeds a predefined threshold, the ROCOP relay is activated, and the system proceeds to check the terminal's voltage (TV). Islanding is declared of the ROCOP and TV thresholds are exceeded. In the reference method (Chauhdary et al., 2024), the Ensemble Kalman Filter (EnKF) is deployed at the PCC or the DG terminal to produce an optimal, noise-free estimate of the system's real-time phasors. During normal grid-connected operation, the strong grid keeps the system behavior predictable, so the difference between the actual measured system voltage/current and the value predicted by the EnKF's internal system model remains close to zero. When islanding occurs, the sudden, fundamental change in system impedance (loss of the stiff grid) causes the measured values to deviate sharply from the model's prediction, resulting in a large, sustained spike in the difference between the actual measured system voltage/current and the value predicted by the EnKF's internal system model. Furthermore, the 3rd harmonic component of the current is monitored as a secondary feature. The magnitude and rate of change of this harmonic are highly sensitive to the shift from the grid's low impedance to the local load's higher, non-linear impedance upon disconnection. It serves to confirm the sustained imbalance characteristic of a true islanding event and distinguish it from momentary non-islanding transients (like faults or load switches).A summary of comparative analysis for the hybrid method is shown in Table 3.

***Table 3:** A Comparison of the Hybrid Island Detection Methods*

Method	Principle	Advantages	Disadvantages	NDZ Size	Typical Detection Time
Passive + Active	Passive indices (e.g., voltage unbalance) trigger active injection (e.g., harmonics)	Small NDZ, reduced disturbance, improved reliability	Higher complexity, parameter tuning needed	Very small	100–200 ms
Active + Communication-Based	Local active injection plus remote transfer-trip or signal exchange	Highly reliable, very small NDZ, suitable for critical grids	High cost, requires a communication infrastructure	Nearly zero	50–150 ms
Multiple Passive Indices	Combine two passive signals, such as ROCOF and phase jump	Low cost, no disturbance, easy to implement	Larger NDZ than active hybrids, sensitive to noise	Moderate	150–300 ms

2.2 Modern Methods

The motivation for incorporating classifiers and signal processing into islanding detection arises from several key limitations of classical methods. To start with, rely on predefined thresholds of voltage, frequency, or harmonic content, which may not always capture the non-linear nature of DG and load interactions. As power systems become more data-rich, modern tools can exploit advanced metering infrastructure (AMI) and phasor measurement unit (PMU) data to enhance islanding detection. Furthermore, passive methods in particular suffer from large NDZs under high quality factor (Q) loads, thereby necessitating the need for AI-driven methods for improving discrimination between islanding and non-islanding events.

This reference (Pavankumar et al., 2024) introduces a novel microgrid islanding detection technique that analyzes the area of the voltage-current Lissajous figure. This method effectively detects islanding and distinguishes it from other disturbances by using an adaptive threshold on the figure's area index. Crucially, it overcomes the NDZ—even with a complete power match—and doesn't require prior knowledge of the network configuration. The reference (P. Kumar et al., 2021) proposed a highly sensitive and fast-acting passive islanding detection technique based on the superimposed angle of negative sequence impedance. The method is specifically designed for a microgrid with a Flexible Topology and various types of Renewable Energy Sources (RES). A modified recursive Discrete Fourier Transform (DFT) is used to extract the fundamental phasor components from the PCC. Deviations of prepossessed PCC measured instantaneous voltage and current from their steady state values, after which the negative sequence of the estimated deviations is used to compute a negative sequence impedance. When the microgrid is islanded, the power balance is severely disrupted, and the system impedance shifts, causing the estimated negative sequence impedance to exhibit a large, measurable deviation from its normal value, whereas during external faults or internal switching transients, the grid's strong influence ensures the estimated negative sequence impedance remains largely unchanged. Consequently, islanding is detected when the calculated negative sequence impedance exceeds a predefined threshold. The technique is proven to successfully discriminate islanding from non-islanding disturbances even at zero power mismatch, effectively solving the (NDZ) problem.

The author of reference (Karegar & Sobhani, 2012) applied the Discrete Wavelet Transform (DWT) to the voltage signal of the local load and compared it to a predetermined threshold for establishing an islanding fault. Similarly, the reference (Ansari et al., 2021) implemented DWT on the measured voltage at PCC and established islanding, also using a predetermined threshold. The approach adopted by the author of reference (Lidula & Rajapakse, 2012) applies the Discrete Wavelet Transform (DWT) to extract features from transient voltage and current waveforms, while a decision-tree classifier leverages the wavelet energy coefficients to differentiate islanding events from other transient disturbances.

The authors of reference (Goriparthy & Geethalakshmi, 2023) formulated an islanding fault detection method entailing a combination of multiple passive parameters using Artificial Neural Networks (ANN). The author of reference (Ali et al., 2021) implemented a cloud-based ANN trained on phasor measurement unit data for fast and accurate islanding detection. Results show that the cloud-based ANN model eliminates the non-detection zone, ensures robustness across different load scenarios, and reduces on-site computational requirements by leveraging cloud resources. Similarly, the author of reference (Nikita et al., 2023) applies a Tri-Layered Neural Network (TLNN) for islanding detection in a solar-wind-based microgrid, demonstrating both promising performance and scalability. According to the author of reference (Fayaz et al., 2021), islanding fault detection can be established by using multiple grid-connected and islanded operating conditions to train a K-Nearest Neighbour (KNN) classifier. However, the method was only validated for grid-connected photovoltaic systems. The reference (Ezzat et al., 2021) analyses instantaneous three-phase voltage and current measurements from the PCC, using DFT to identify harmonic components, focusing on the second-order harmonic due to its observed prominence during islanding operation. Multiple features are extracted from the second-order harmonics found after which KNN is implemented as a classifier for distinguishing islanding and non-islanding events. In the reference (S. Mishra et al., 2021), the measured voltage signal from the PCC of the microgrid is processed using Empirical Mode Decomposition (EMD), which breaks down the signal into several Intrinsic Mode Functions (IMFs). Several statistical measures are computed from the second IMF and fed to an improved KNN classifier, which detects islanding with higher accuracy. The author of reference (Al-Momani et al., 2023) proposes a novel approach for detecting islanding in power systems, specifically for Doubly Fed Induction Wind Turbine (DFIG) within a micro-grid setup. The core idea is to use a Feedforward Artificial Neural Network (ANN) as a pattern classifier to quickly and accurately determine if the DFIG has become isolated from the utility grid. The study investigates and compares the performance of various ANN structures based on different input data from the PCC and training algorithms. It was concluded that the Cuckoo Optimization Algorithm (CA) yielded the best islanding detection results with three-phase power measured from the PCC as input.

In reference (Chauhdary et al., 2025), the author proposes a highly accurate and computationally efficient hybrid passive method for detecting islanding events in microgrids by combining an Unscented Kalman Filter (UKF) for noise filtering and state estimation with a Deep Neural Network (DNN) for classification. To reduce measurement errors before classification, the UKF function is implemented as a state observer to analyse the measured voltage signals at the DG terminal or the (PCC), after which the UKF-estimated voltage is fed into the DNN to calculate the DNN Residual Index (DNNR). This novelty allows the DNN to learn the temporal and nonlinear characteristics of the voltage signals, after which an islanding fault is established when DNNR crosses a predefined threshold. The reference (Baghaee et al., 2020) fed PCC measured power, voltage, current, and harmonic distortion as input to a Support Vector Machine algorithm (SVM), which was effective in distinguishing islanded operation from grid-connected conditions. The author of reference (Chakravorti et al., 2019) proposed a combination of Parameter Adaptive Variational Mode Decomposition (PAVMD) and a Robust Regularized Random Vector Functional Link Network (RRVFLN) for recognizing island events, of which the PAVMD was optimized by the firefly algorithm. The scheme was shown to perform better than SVM.

In reference (Osama et al., 2025), the author deployed a Convolutional Neural Network (CNN) on active current and voltage measurements taken at the PCC, during which the CNN classifies the system state as either "grid-connected" or "islanded."Islanding detection in microgrids is enhanced by the author of reference (Ozcanli & Baysal, 2022) using two proposed methods: 1 a 1-dimensional CNN and a combination of CNN and Long Short-Term Memory (LSTM) models, achieving high accuracy and superior robustness while remaining cost-effective for real-time use. The reference (Bukhari et al., 2021) proposes an LSTM-based passive detection scheme that employs ROCOP and ROCOF at the PCC as input. In reference (Xia et al., 2022), the author established a new islanding detection algorithm by extracting multiple features from the inverter output current and voltage at the point of common coupling (PCC) measurements at PCC and feeding them into an LSTM network optimized with an integrated attention Layer that helps to discriminate between islanded and grid-connected operations of the microgrid. The LSTM-based approaches all showed a high success rate with reduced NDZ.

The author of reference(Hariprasad et al., 2023) proposes an improved active anti-islanding scheme to quickly and accurately detect the disconnection of s DG from the main utility grid. The detection algorithm is built around a fuzzy rule base initialized by a decision tree using ROCOF, ROCOP, and frequency deviation thresholds from the DG's output. The methodology in reference (Venkata Pavan Kumar et al., 2023) merges the strengths of decision trees with fuzzy logic to achieve a reliable and fast decision, especially in interoperable microgrid clusters designed for high-density urban settings. The precise, numerical values of the PCC estimated ROCOF and ROCOV are converted into linguistic variables (e.g., "fast," "medium," "slow") using predefined membership functions. This allows the system to handle the inherent imprecision and uncertainty of real-time measurements. Next, the linguistic output is converted back into a crisp, numerical value (the detection index). The decision tree analyses a large dataset of simulated islanding and non-islanding events to learn the most effective rules that accurately map the input features (ROCOF/ROCOV) to the correct output (islanding/non-islanding).

The author of reference (D. Kumar, 2022) proposed a probabilistic, predictive model approach specifically designed to maintain reliability when communication is interrupted or data is missing from Micro Phasor Management Units (μPMUs). It measures eight key parameters (including voltage, frequency, and ROCOF) and uses a Principal Component Analysis (PCA) for dimensionality reduction. This processed data is fed into an Artificial Neural Network (ANN), which initiates the predictive model to estimate the probability of islanding. By using specialized sub-algorithms (including a posterior estimation based on Bayes' theorem for missing data), the system confirms islanding when the calculated probability exceeds a fixed threshold, ensuring robust detection despite network instability.

In reference (Pal et al., 2025), the proposed scheme tackles the NDZ by treating islanding detection as an image classification problem. The procedure involves three innovative steps: first, the Total Harmonic Distortion (THD) signals from the three-phase voltages and currents, measured at the PCC, are converted from one-dimensional time series data into two-dimensional scalogram images using the Continuous Wavelet Transform (CWT). Second, distinctive patterns are extracted from these scalogram images using Histogram of Oriented Gradient (HOG) descriptors, which effectively capture subtle signal changes related to islanding. Finally, these robust HOG features are fed into a random forest classifier, which is trained to accurately differentiate between islanding and non-islanding events. On the other hand, the reference (Dutta et al., 2021) proposes an islanding detection method for microgrids based on a combination of the Discrete Fractional Fourier Transform (DFrFT) and a random forest classifier, an ensemble algorithm. Synchronized measurements from PMUs mounted on solar generator buses are analysed across time and frequency domain using DFrFT and afterwards, fed to the RF classifier. The decision, i.e., islanded or non-islanded, is based on the majority vote of all the individual decision trees within the forest. Additionally, the reference method (S.

Mishra et al., 2024) measures various electrical quantities at the PCC and applies a rigorous feature selection process to identify the minimum set of critical features that are most sensitive to the islanding event. These selected features form the final, reduced training input. The classification is performed by a novel optimized random decision forest**.** The model processes the reduced feature set and provides a fast, accurate output that not only detects the islanding state.

The reference method (M. Karimi et al., 2023) extracts superimposed harmonic spectra from three-phase voltage signals at the PCC using a full-cycle Discrete Fourier Transform (DFT) sampled at 1 kHz. These spectra capture dynamic changes while filtering out steady-state harmonics. A one-class k-Means Data Description (k-MDD) classifier is then trained offline using simulated islanding events to identify the harmonic signature of islanding conditions. In real time, new voltage data are processed, and their harmonic patterns are compared with trained cluster centroids to determine whether islanding has occurred.

The method proposed by the reference (Zhi et al., 2023) establishes an island fault for a DC microgrid by implementing an Adaptive Boosting (AdaBoost), an ensemble learning algorithm to serve as a classifier. A Feature screening method is used to analyse various measured electrical parameters at the PCC and select only the key feature electrical quantities that are highly sensitive to islanding. The selected feature set is fed into the AdaBoost, which is primarily used for binary classifications, in this case: islanded or non-islanded. A final check methodology is further deployed to ensure a secure and dependable final tripping decision for results indicating possible islanding. The reference (R. Chen et al., 2023) presents a method that uses CatBoost (Categorical and Boosting), an advanced ensemble learning algorithm combined with statistical analysis to detect islanding in microgrids. The Spearman correlation coefficient is used to analyse the correlation between multiple electrical feature quantities measured at the PCC and the microgrid's operating state (grid-connected vs. islanded). Only the electrical feature quantities that exhibit a strong correlation with the islanding state are extracted and used as inputs for the next stage. The next stage entails implementing the advanced ensemble learning algorithm for training the chosen electrical features to both establish suitable thresholds for the selected electrical features as well as distinguish between islanded from non-islanded scenarios.

The methodology established in the reference (Akıl et al., 2025) is an intelligent islanding detection technique that leverages the Random Vector Functional Link Network (RVFLN) classifier for fast and robust classification across diverse microgrid conditions. This approach begins by performing feature extraction on locally measured voltage and current signals to capture the transient changes that occur when the microgrid disconnects from the utility grid, focusing on parameters like ROCOF, ROCOV, and sequence components. The extracted features are then input into the RVFLN model, which is a type of single-hidden-layer neural network designed for extremely fast learning because its input weights are randomly assigned and not iteratively trained. Crucially, the RVFLN architecture includes a direct link between the input and output layers, which enhances the model's stability and generalization capability. This intelligent classification process is shown to perform better than Random Forest, SVM, and k-NN.

2.3 Practical Challenges

Islanding detection is a vital requirement for ensuring the safe and reliable operation of DG systems. Despite the availability of numerous detection techniques—ranging from passive and active schemes to communication-based and hybrid approaches—practical implementation in real-world power systems remains a significant challenge. In this section, we discuss some practical challenges in implementing islanding detection methods.

One of the foremost challenges in islanding detection is the cost of deployment. Passive and active methods are generally cost-effective, as they require minimal hardware beyond inverter-level control adjustments. However, their reliability decreases under high-quality factor (Q) load conditions, leading to potentially unsafe NDZs. Communication-based schemes (e.g., power line carrier, SCADA-based, or synchrophasor-assisted methods) provide high accuracy but are significantly more expensive due to the need for dedicated communication infrastructure, monitoring devices, and maintenance. Hybrid schemes attempt to balance cost and performance, but integration complexities still raise initial and operational expenditures. Thus, utilities must weigh the financial feasibility of widespread deployment, especially in regions with extensive DG penetration.

Some detection methods intentionally inject disturbances into the system to accelerate islanding identification. While effective in reducing the NDZ, these methods pose power quality concerns:

Active methods such as Sandia Frequency Shift (SFS) or Active Frequency Drift (AFD) may introduce harmonics, frequency deviations, or voltage fluctuations. Frequent or aggressive perturbations can impair sensitive loads, degrade customer power quality, and even lead to false tripping under normal operating disturbances. Hence, the trade-off between fast and accurate detection and preservation of power quality remains a core challenge in method selection.

International and regional standards play a decisive role in shaping acceptable islanding detection strategies. The IEEE 1547 standard from the reference (IEEE, 2020) mandates that DG units must detect and cease to energize an island within 2 seconds of its formation. The IEC 62116 standard from the reference (IEC, 2014) provides testing procedures for evaluating the effectiveness of islanding prevention methods in grid-connected photovoltaic (PV) systems. Meeting these standards is not always straightforward. Passive methods may fail in scenarios that fall within their NDZ. Active methods may pass compliance tests but risk non-conformance in terms of power quality. Communication-based methods often exceed compliance requirements but may face interoperability challenges in multi-vendor or multi-utility environments.

In addition, critical operational requirements—Low-Voltage Ride-Through (LVRT) in (Pourbeik, 2023) and islanding detection—often conflict with each other in grid-connected inverter-based systems. While LVRT mandates that inverters remain connected during voltage disturbances, islanding detection schemes typically require rapid disconnection under similar conditions. This conflict can cause instability, loss of synchronization, and violation of grid code requirements. Overly sensitive anti-islanding detection can degrade LVRT performance, while relaxed settings risk prolonged island operation. The controller’s response time, phase-locked loop (PLL) behaviour, and reactive current injection algorithms are key factors influencing this interaction.

The transition toward renewable-dominated systems amplifies the complexity of islanding detection. With high DG penetration, generation-load balancing becomes more frequent, increasing the likelihood of situations where NDZ is large. Variability of solar PV and wind generation complicates the effectiveness of conventional detection methods, which rely on predictable imbalance signals. Inverter-dominated systems reduce system inertia, making frequency-based detection less reliable. Hybrid and AI-based methods offer promise, but their scalability, robustness to diverse grid conditions, and cybersecurity risks remain under investigation.

2.4 Future Trends

Future trends in islanding detection for DG and microgrids are being driven by the increasing complexity of smart grids, the high penetration of inverter-based renewable energy sources (RES), and the need for greater detection speed, accuracy, and reliability. Some future trends are discussed in this section:

One of the most promising directions is the application of machine learning (ML) and artificial intelligence (AI). By training algorithms on large datasets of system disturbances, ML classifiers, neural networks, and deep learning models can distinguish islanding from other transient events with high accuracy. These approaches significantly reduce the NDZ, accelerate detection, and improve robustness under noisy and complex operating conditions. Hybrid AI models that combine feature extraction, advanced ensemble methods, with deep networks are expected to dominate future solutions.

Future methods will rely heavily on advanced signal processing techniques. Approaches such as wavelet transforms, Gabor analysis, and fractional Fourier transforms are being explored for their ability to capture subtle time–frequency signatures of islanding events. These methods enhance detection under challenging conditions, such as high-Q loads or near power balance scenarios, where traditional methods fail. The trend is toward extracting multi-domain features that improve sensitivity without adding excessive computational burden.

While hybrid methods already exist, the next generation will be more adaptive and intelligent. Future schemes are expected to combine passive and active detection with AI-based decision-making, applying each method dynamically based on system conditions. For instance, passive methods could serve as the primary filter, while active perturbations or communication checks are triggered only in ambiguous cases. Such adaptive approaches minimize power quality degradation, reduce false tripping, and ensure reliable detection across a wide range of scenarios.

Efficiency is becoming as important as reliability. Future islanding detection will increasingly be event-triggered—activating advanced algorithms only when anomalies are observed—rather than continuously injecting signals or computing heavy metrics. This shift improves detection speed and conserves computational and energy resources. Real-time frameworks capable of detection within milliseconds will be essential for grids with high renewable penetration, where fast response is critical to system stability.

Future systems will move beyond simple passive monitoring and fixed-parameter active methods toward intelligent control strategies like Model Predictive Control (MPC), Data-Based/Machine Learning Methods, with the essence of developing smarter, more adaptive, and less intrusive control techniques to manage the conflict between staying connected (LVRT) and safely disconnecting (AI).

The expansion of smart grid technologies provides new opportunities for islanding detection. Phasor Measurement Units (PMUs), smart meters, and IoT-enabled sensors offer synchronized, distributed data that can be used to detect islanding more accurately. Integration of these devices allows for wide-area monitoring and distributed intelligence, reducing reliance on centralized communication. Moreover, existing infrastructure can be repurposed for detection, lowering deployment costs.

A persistent goal in islanding detection is the elimination of the NDZ. Future solutions will focus on reducing NDZ to near zero, even under zero power mismatch conditions. At the same time, robustness against practical issues such as noise, load switching, unbalanced conditions, and harmonic distortion will be emphasized. By combining advanced sensing, AI, and hybrid schemes, future systems aim to achieve reliable detection under real-world complexities.

As DG penetration increases globally, cost becomes a key constraint. Future detection methods will emphasize cost-effectiveness, prioritizing schemes that require minimal additional hardware and can operate with existing control or measurement devices. Scalable solutions that can adapt to microgrids, virtual power plants, and large interconnected systems will also be essential.

Future trends are shifting from detection alone to integration with system control. Islanding detection will increasingly be tied to broader resilience frameworks, including intentional islanding, load shedding, and microgrid reconfiguration. Instead of merely disconnecting DG, advanced schemes will enable coordinated responses that maintain stability and ensure continued supply to critical loads during disturbances.

Another future trend is the growing push toward standardization and benchmarking. As methods proliferate, regulators and industry bodies are working to define clear performance standards for NDZ size, detection time, and reliability. Simulations will be complemented by field trials and real-world deployments in microgrids to ensure practical feasibility. This trend will help narrow the gap between laboratory research and industrial application.

3 Conclusion

Islanding detection remains one of the most critical challenges in the integration of DG into modern power systems. With the growing penetration of renewable energy sources such as photovoltaic (PV) systems and wind turbines, the reliability and speed of islanding detection are increasingly important for ensuring safety, maintaining power quality, and achieving compliance with evolving grid codes. Traditional methods—passive, active, communication-based, and hybrid—have advanced considerably, but each suffers inherent trade-offs.

The remote or communication-based techniques offer very fast and robust detection of islanding faults and are further scalable to systems with multiple DG units. Conversely, they require high implementation and maintenance costs due to the need for communication infrastructure. They further lead to challenges like increased system complexity, vulnerability to cybersecurity threats.

The passive methods require Low implementation cost since they require no additional hardware. They do not introduce perturbations into the power system, thereby preserving power quality. Furthermore, they are easy to implement and widely applicable across DG technologies. On the other hand, passive methods are prone to a large NDZ, particularly when the local load and generation are closely matched. They may fail under high-quality factor (Q) load conditions. Their detection speed is relatively slow compared to active and communication-based methods. Moreover, they are susceptible to nuisance tripping during normal grid disturbances such as voltage dips or frequency fluctuations.

The active methods have significantly smaller NDZ than passive methods. They are reliable even under load-generation balance scenarios, unlike the passive methods. Additionally, they provide faster detection compared to purely passive techniques. Nevertheless, they require a deliberate perturbation of the DG, which can negatively affect power quality as well as cause a potential reduction in the overall efficiency of the DG. Conversely, active methods require careful tuning to avoid false tripping or excessive PQ degradation. Also, their cost is slightly higher than passive methods, as more sophisticated control logic is required.

Hybrid methods combine two or more techniques, typically passive with active, or active with communication-based methods. The idea is to exploit the strengths of each method while minimizing its weaknesses. This offers the advantage of reduced NDZ compared to passive methods. Their impact on power quality is less compared to purely active methods. In addition, they offer a balanced compromise between cost, reliability, and detection speed. However, they offer higher complexity in design, requiring careful coordination between detection mechanisms. They are costlier than single-method approaches.

Practical implementation of islanding detection faces persistent challenges related to cost, power quality, regulatory compliance, and adaptability to modern high-DG grids. While no single method provides a universally optimal solution, the trend is moving toward hybrid and intelligent detection approaches that aim to minimize NDZ while satisfying standards and maintaining acceptable power quality. Addressing these challenges requires continued collaboration among researchers, utilities, equipment manufacturers, and regulators to ensure safe and resilient grid operation in the era of renewable integration.

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