

A Review of Islanding Detection Techniques for Inverter-Based Distributed Generation [†]

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Abstract: The classical problem of islanding detection in distributed generation falls into the commonly used categories known as passive, active, and hybrid techniques. These approaches vary in terms of their accuracy, security, and dependability. Detecting islanding in modern inverter-based distribution systems is of the utmost importance to ensuring the protection of equipment, ensuring the safety of workers, and preventing operational and cascaded faults when the system is specially subjected to renewable integration. This research paper presents a technical comparison of the aforementioned techniques, discussing their detection rate, Non-Detection Zone (NDZ), distinct topologies, and their effectiveness in integration for low-frequency grids. The review offers a thorough analysis comparing the key attributes found in the current literature while also highlighting the forthcoming needs for advanced management, optimization, and control technologies. These technologies are crucial to effectively tackling the difficulties that arise from integrating renewable energy sources into established grid systems.

Keywords: islanding detection; distribution generators; inverters; active; passive; hybrid



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1. Introduction to the Islanding Detection Problem

Renewable energy capacity additions climbed by 17% in 2021, reaching a new high of 314 GW. Between 2022 and 2027, the capacity of all renewable energy sources is expected to rise by 2400 GW. Advanced control, optimization, and management technologies are necessary to solve the difficulties and hazards caused by this expansion. Effective islanding detection is necessary for protecting the well-being of both equipment and workers and avoiding unnecessary excursions that can result in malfunctions. According to IEEE, “islanding is defined as a condition in which a portion of the utility system remains energized while isolated from the rest of the utility system and contains both load and distributed resources.” [1].

Islanding detection techniques have always been a critical concern ensure the safety and reliability for the modern grid with the integration of low inertial distributed energy resources. The techniques can finely be classified under passive and active methods which can be sub-characterized to local and remote based on the methodology based on their control response. The DER and the grid are connected to power the load at the Point of Common Coupling (PCC), as shown in Figure 1. The main issue with islanding detection is the presence of non-detection zone (NDZ). This is when the island grid cannot detect an isolation from the main grid, which is referred to as a non-detection zone. This is caused by a phenomenon known as a power mismatch, when islanding happens but the power output from the DER is not sufficient and rather equally matches the load requirement.

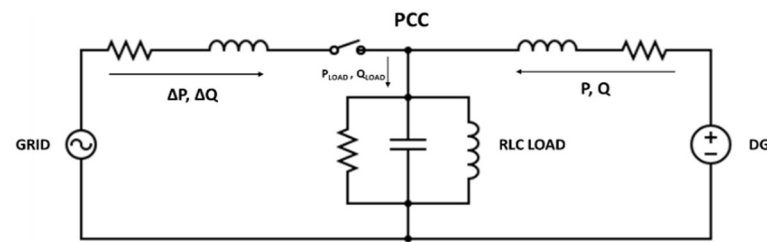


Figure 1. IEEE1547 standard model [2].

2. Classification of Islanding Detection Techniques

As mentioned, islanding is further divided into three main classes passive, active, and hybrid, as shown in Figure 2. Overvoltage and over/under-frequency approaches use voltage-sensing devices to detect overvoltage and under voltage. The over/under frequency method is useful for identifying islanding incidents when load fluctuations or grid disturbances cause anomalous frequency levels as shown in Table 1. However, when the load changing rapidly, the active power mismatch ($\Delta P/P$) may be challenging [3,4]. On the other side, ROCOF passive islanding detection requires monitoring the grid frequency to isolate a portion of it when the RoCoF rises over a threshold, but this can experience transient peaks due to disturbances [4]. Heading toward a voltage imbalance occurs when there is an uneven distribution of voltages among the three phases of a three-phase electrical system, leading to voltage swings and potential equipment damage. Table 2 presents a comprehensive literature review of all methods comparing their unique features and research gap. Passive islanding technology checks voltage unbalance and disconnects the DER from the primary power grid when it reaches a specified threshold [5,6].

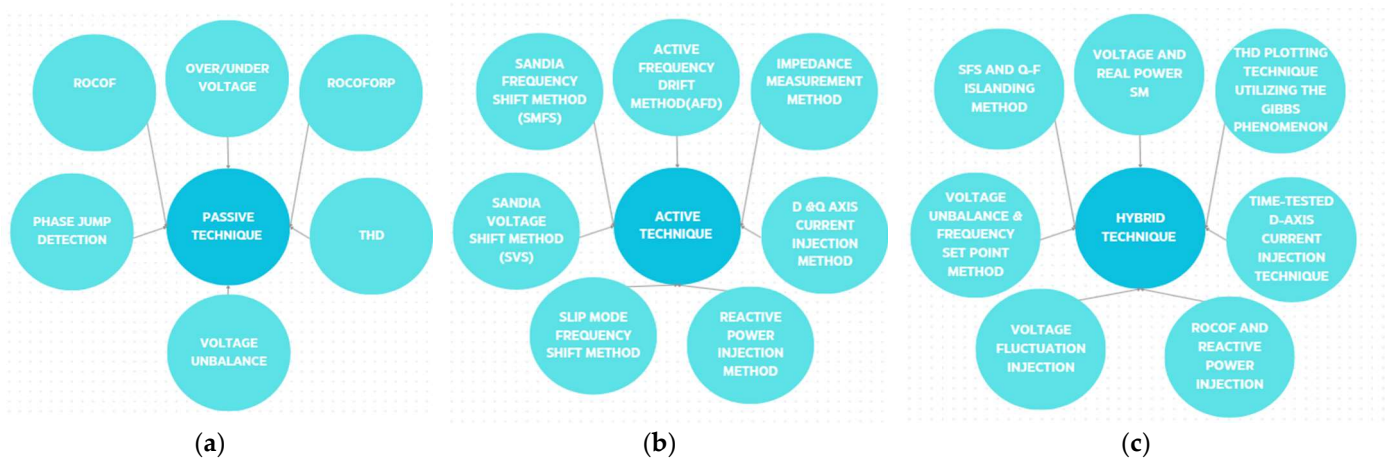


Figure 2. (a) Major Passive IDT. (b) Major Active IDT. (c) Major Hybrid IDT.

Table 1. Comparison of International Standards for islanding detection schemes.

Parameters	IEC 62116	IEEE 1547	IEEE 929
Quality factor	1	1	2.5
Required islanding detection time	$t < 2 \text{ s}$	$t < 2 \text{ s}$	$t < 2 \text{ s}$
Normal frequency range	$(f_0 - 1.5 \text{ Hz}) \leq f \leq (f_0 + 1.5 \text{ Hz})$	$59.3 \text{ Hz} \leq f \leq 60.5 \text{ Hz}$	$59.3 \text{ Hz} \leq f \leq 60.5 \text{ Hz}$
Normal voltage range	$85\% \leq V \leq 115\%$	$88\% \leq V \leq 110\%$	$88\% \leq V \leq 110\%$

Additionally, phase jump detection indicates that there is a shift in the phase angle between the output voltage and current on the DER side. When the phase error surpasses a specific limit, islanding is identified [7]. Evaluating the effect of harmonic distortion

levels before and after the construction of the island is part of the harmonic distortion islanding technique. If the distortion caused by the harmonics levels is higher than a set limit, islanding has taken place [8]. The PCC measures frequency over reactive power using the ROCOF over reactive power technique (ROCOFRP). This method is appropriate for practical implementation since it detects islanding down to very small power mismatches of 0.05 MW and 0.05 MVar, which considerably improves accuracy. It is also low-cost and has no impact on power quality [9].

Active islanding detection techniques in DERs induce power quality constraints by causing a minor perturbation in the power signal. This is done in order to achieve smaller non-detection zones compared to the passive methods [10–12]. The active frequency drift (AFD) maintains a steady power factor and grid frequency when connected to the grid, but when it is not, a slight change in the current reference allows it to gradually get closer to the established criteria for detecting islanding [13–16]. The Sandia Frequency Shift Method (SMFS) is explained by [17]. This technique extends the dead time of the inverter by adding a tiny current to the output, which raises the output current frequency. After this frequency rise, the over-frequency safety limit in the grid-islanded mode is achieved. This system's non-detection zone (NDZ) is less than that of the preceding active approach.

Additionally, the Sandia Voltage Shift (SVS) approach also solves power fluctuations and inverter outages. For islanding detection, the Sandia Voltage delivers positive feedback voltage to the Point of Common Coupling (PCC). It is one of the most effective active feedback-based systems, detecting islanding when the amplifier's voltage reaches a certain threshold, but when linked to the grid, it can have an impact on the quality of the electricity [17]. Xie et al. discussed the reactive power injection method, which detects islanding when in the grid-disconnected mode. The reactive power injection approach uses a rotating reference [18]. It deals with the problem of small NDZs by introducing reactive power and altering the rotational frame of reference [4,11]. A comprehensive comparison of NDZ and detection time for Passive and active methods is presented in Figures 3–6. Here the idea and calculations of non-detection zones and detection rates are presented in a numeric bar graph. We have estimated the data of all evaluations of different authors that have given their results adjectively or comparatively as shown in Table 2.

The voltage imbalance and frequency set point approach are hybrid detection method that uses both THD and VU passive parameters to accurately identify islanding events during load shifts [4,19]. Hybrid Islanding Detection (HID) is an effective approach that outperforms passive single-parameter approaches, but it can be misidentified if large loads are switched. To solve this issue, a VU- and ROCOF-based HID has been developed; it only detects islanding when both the VU and ROCOF are higher than a predetermined threshold [4]. Arif et al. explored a deep-learning-based online hybrid detection technique [20].

Table 2. Recent Literature Review: Islanding Detection Methods and Characteristics.

S. No.	Paper	Detection Duration	System Topology	Technique	Non-Detection Zone (NDZ)	Pros and Cons
1.	Jang and Kim (2004) [6]	53 ms	Multiple-inverter-based DER (IBDER)	Voltage unbalance	Large	Simple and fast
2.	Meshram and Kumar (2020) [8]	0.01 s	Multiple IBDER	THD	More	NDZ is not zero
3.	Raza et al. (2015) [9]	200 ms	Multiple IBDER	ROCOFORP	Negligible	-

Table 2. Cont.

S. No.	Paper	Detection Duration	System Topology	Technique	Non-Detection Zone (NDZ)	Pros and Cons
4.	Bharti et al. (2021) [19]	$4 \text{ ms} \leq t \leq 2 \text{ s}$	Multiple IBDER	Over/under voltage	Large	-
5.	Reddy et al. (2020) [21]	32 ms	Multiple IBDER	ROCOFOROP	Zero	It perfectly detects islanding
6.	Shrestha et al. (2019) [22]	0.03 s	Multiple IBDER	Over/Under voltage	Large	-
7.	Abyaz et al. (2019) [23]	$\leq 1 \text{ s}$	Single IBDER	ROCOF	-	Dependent on system inertia
8.	Somalwar et al. (2020) [24]	$\leq 2 \text{ s}$	Multiple IBDER	PJD	-	Simple and fast detection
9.	Naraghipour et al. (2020) [25]	0.1 s	Multiple IBDER	ROCOFORP	NDZ is not equal to zero	-
11.	Barkat et al. (2020) [11]	<100 ms	Single IBDER	ROCOF	Small	Simple and fast detection
12.	Somalwar et al. (2020) [24]	0.11 s	Multiple IBDER	AFD	Massive	The simplicity of AFD's implementation in inverters with microcontrollers is a benefit
13.	Barkat et al. (2020) [11]	-	Multiple IBDER	AFD	Greater	Wider Non-Detection Zone (NDZ)
14.	Bharti et al. (2021) [19]	$\leq 2 \text{ s}$	Multiple IBDER	Active Frequency Drift (AFD)	Greater	It is impossible to identify islanding under balanced loading. It only detects islanding under resistive loads
15.	Gottapu et al. (2022) [26]	-	Single IBDER	(SFS)	Smallest	Negligible NDZ.
16.	Wang et al. (2020) [17]	135 ms	Single IBDER	Sandia Frequency Shift Method (SFS)	-	There are still issues with network reliability and power quality
17.	Gavinda and Jena (2019) [27]	0.18 s	Single DG	Reactive Power Injection method	-	Rapid detection, simplicity of use, and many inverters
18.	Mohanty et al. (2023) [15]	$\leq 0.5 \text{ s}$	Multiple inverters based DG	Slip Mode Frequency Shift Method (SMFS)	Wider or fewer	Decent ID strategy with slightly NDZ
19.	Kumar (2021) [28]	longest time for islanding detection	Single inverter-based DG	IM (Impedance measurement)	Negligible	1. Harmonic generation 2. It is simple and affordable.
20.	Gaurav and Agnihotri (2021) [29]	$\leq 2 \text{ s}$	Multiple DG wind & PV	D & Q axis injection	-	Detection rate is very fast.
21.	Nikolovski et al. (2020) [16]	0.2 s	Multiple inverters based DG	Sandia Voltage Shift Method (SVS)	Least	Low NDZ, straightforward, and affordable.

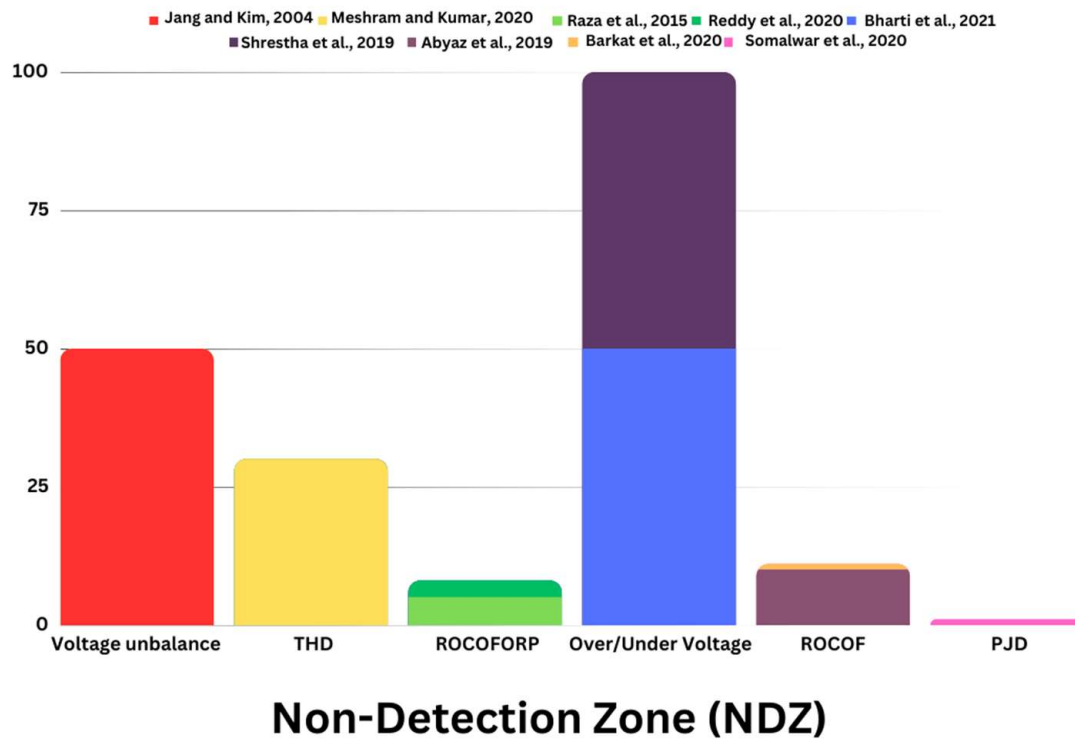


Figure 3. Passive methods—non-detection zone [6,8,9,11,19,21–24].

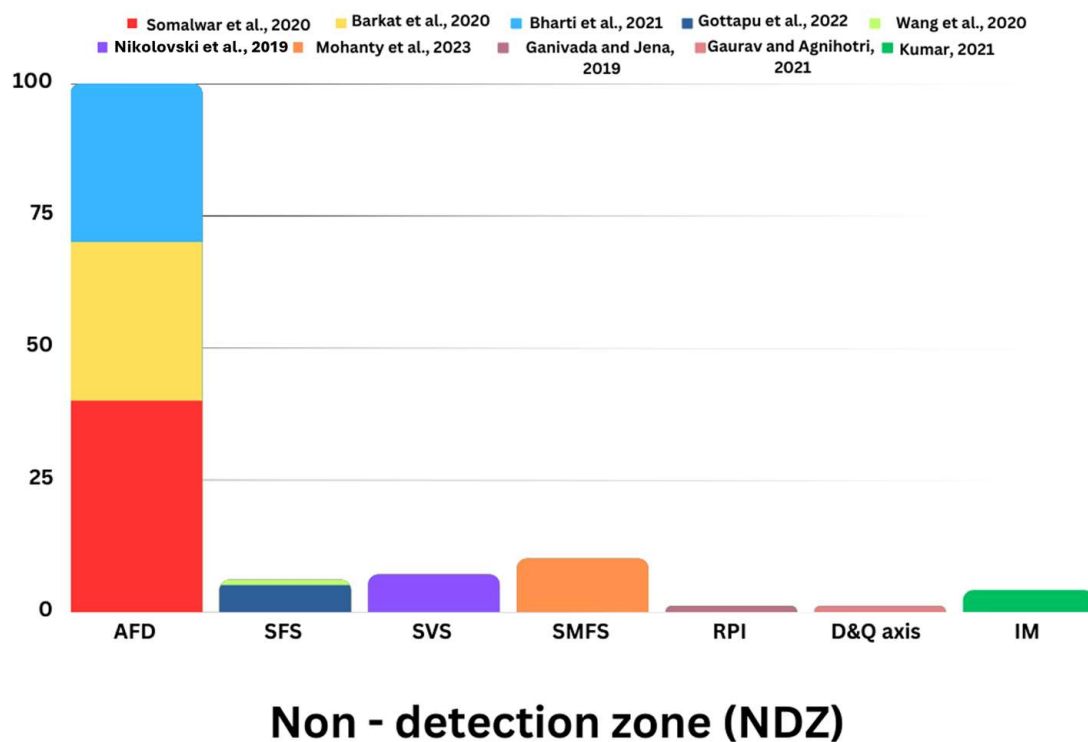


Figure 4. Active methods—non-detection zone [11,15–17,19,24,26–29].

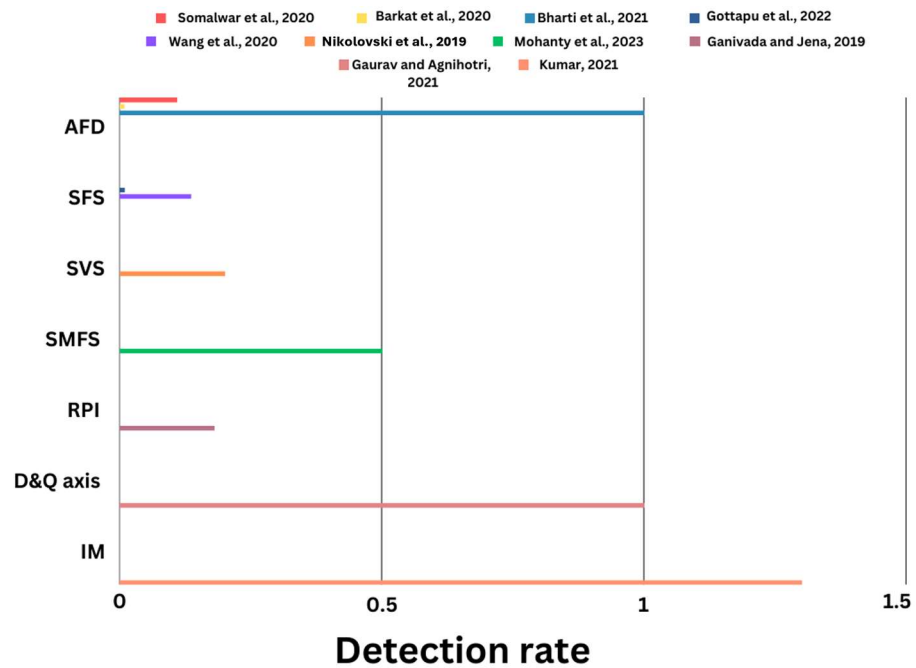


Figure 5. Passive method—detection time [11,15–17,19,24,26–29].

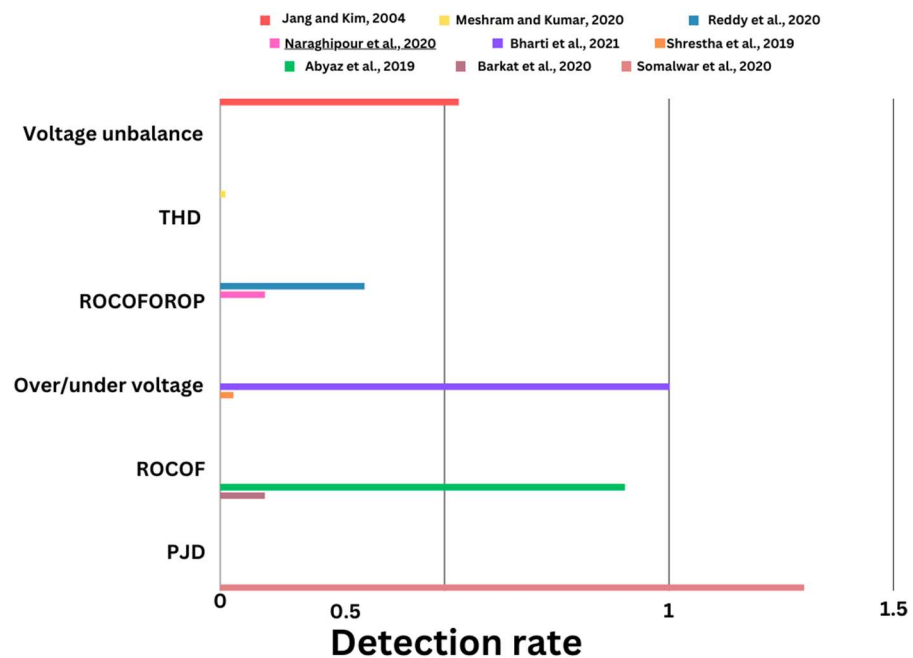


Figure 6. Active methods—detection time [6,8,11,19,21–25].

3. Conclusions

In summary, passive systems, which rely on grid characteristics, are cost-effective but may struggle with load variations and have larger non-detection zones, while active methods can impact power quality but offer faster identification. Hybrid approaches aim to improve accuracy and reduce non-detection zones by combining active and passive techniques. Among hybrid approaches, the most desirable methodology balances accuracy and computational efficiency. It combines active power and voltage shift analyses with ROCOV (Rate of Change of Voltage) analyses. In contrast, single-parameter techniques are surpassed by the HID (Harmonic Impedance-based Discrimination) methodology, which

utilizes voltage imbalance and ROCOF (Rate of Change of Frequency) thresholds. The choice of approach should consider the study's objectives, system characteristics, and any specific challenges. A thorough review of the literature is necessary. Overall, a hybrid method holds promise for developing a dependable islanding detection system that ensures the secure integration of distributed generation.

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