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An extensive review of islanding detection approaches in microgrids for distribution generations

Resna S. R., Devi Vighneshwari B.
Department of Electrical and Electronics Engineering, The Oxford College of Engineering, Bangalore, India

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ABSTRACT

Microgrids integrated with distributed systems provide several benefits to the power grid, including faster detection times, superior power quality, and energy savings. Microgrids are managed using various methodologies in both grid-connected and island states. Microgrids must detect inadvertent islanding to protect individuals and prevent device damage. Monitoring and identifying magnitude anomalies are the foundation of the majority of islanding detection approaches (IDAs). This study summarizes the IDAs used in microgrids. An islanding fault is a microgrid that inadvertently disconnects from itself owing to a problem in the utility grid. A through categorization of IDAs is provided, with a focus on both local and remote approaches. Local IDAs can be further classified using passive, active, and hybrid methods. Furthermore, the power-quality effect, nondetection zone (NDZ), detection time (DT), and error detection rate (EDR) statistical comparison of the IDAs is examined. The benefits, drawbacks, and research gaps in the current work are evaluated. Lastly, challenges and recommendations for future research are highlighted.

Corresponding Author:

Resna S. R.
Department of Electrical and Electronics Engineering, The Oxford College of Engineering
Bangalore, India
Email: resnatoce@gmail.com

1. INTRODUCTION

Compact power plants, known as distributed generations (DGs), are thought to be a viable way for traditional power systems to address their financial and environmental problems. With DGs, there are financial benefits in lowering the distance and amount of electric power lines, as well as the power lost during transmission. This is because energy can be produced close to its point of consumption. Integration of DGs is constrained, nevertheless, in that they must comply with the associated distribution systems' operational requirements. The process known as anti-islanding requires DGs to recognize the islanding scenario and instantly cease generating electricity whenever the grid cuts off communication between the distribution infrastructure and DGs [1], [2]. Among these difficulties, islanding scenario identification is one of the most widely recognized. When islanding occurs, safety switches and interrupters frequently cause a portion of the power distribution system with DGs to disconnect from the primary grid inadvertently. The proper diagnosis of the islanding issue must be made. Nonetheless, it may harm DGs and their apparatus [3], [4]. The increasing popularity of distributed generators (DGs) has brought significant attention to the concept of microgrids (MGs) for power distribution. MGs must accurately identify islanding scenarios. Implementing an effective strategy to detect inadvertent islanding situations in MGs is crucial, considering their operation, supervision, safeguarding, and security techniques will differ in the deliberate island state and grid-connected configurations [5]. Two types of islanding detection approaches (IDAs) have been suggested for MGs at present: remote and local approaches [6], [7]. Remote IDAs rely on cellular networks and technology, as their operation depends on metrics and data gathered from both the utility grid and microgrid perspectives. This requirement increases both the cost and complexity compared to local IDAs, which rely solely on local observations and data. Additionally, there are three types of local approaches: passive, active, and hybrid. Passive approaches, despite impacting MGs, make decisions based on local observations and predetermined thresholds. [8], [9], In contrast, active approaches often introduce disturbances into the MG and make decisions based on the resulting changes in local observations [10]–[12]. A hybrid approach combines elements of both active and passive strategies [13]. Passive approaches are the least expensive, least complicated and most rapid in detecting local islanding; in contrast to active schemes, they also have no impact on power quality. In contrast to active and hybrid approaches, passive approaches often have a larger nondetection zone (NDZ). This flaw can be particularly apparent in MGs with DGs that use inverters. Certain studies have tried to enhance the effectiveness of passive IDAs for MGs using inverter-based DGs [14].

This section discusses the problem statement related to islanding phenomena in distributed generation systems. There are two types of islanding: deliberate and inadvertent. While inadvertent islanding happens due to various system alterations, deliberate islanding is a circumstance that is partially premeditated. The main issue that the system faces as a result of the inclusion of DGs is inadvertent islanding, which can result in many challenges, such as a lack of establishing and two-way circulation of power, employee security being compromised, disruptions to the frequency and voltage synchronization of synchronous power sources and conversion devices, and challenges with power quality as a result of the opposite power flow occurrences. The IDA is an essential and challenging task in consolidated power distribution infrastructure. When DG integration increases, the importance and complexity of inadvertent islanding identification will rise. Many innovative IDAs have been modelled and constructed to tackle such challenges. When correctly used, the regulations for both deliberate and inadvertent identification of islanding offer secure processes and mitigate the consequences of DG islanding. Microgrids must detect inadvertent islanding with minimal power quality issues, less nondetection zone and minimal cost to protect individuals and prevent device damage.

Nevertheless, as seen by the numerous IDAs that have been submitted over decades, islanding remains an open research problem. Several study initiatives were launched to solve the issue surrounding inadvertent islanding within the microgrid and reduce the difficulties associated with IDA. This research work provides an extensive examination of the several IDAs documented in the literature.

The review paper is divided into the following sections: The thorough classification of IDAs according to previous research and an assessment of their effectiveness is explained in section 2. In section 3, the literature is compared regarding merits and demerits, followed by research gaps and future directions in the subject of IDAs. Lastly, the article is concluded in section 4.

2. EXISTING WORKS OF ISLANDING DETECTION APPROACHES

The two primary islanding detection approaches (IDAs) categories are local and remote. Local islanding detection approaches (LIDAs) are categorized into passive, active, and hybrid types based on factors such as NDZ, power quality, error detection rate, detection speed, and effectiveness in different inverter scenarios. Utilities widely use passive islanding detection approaches (PIDAs) because of their cost-effectiveness and minimal impact on power quality. These approaches, nevertheless, possess a wide NDZ, and threshold adjustment is difficult. Various transformations and advanced classifiers have been applied in the current works to get around the PIDA's drawbacks. The detailed classification of IDAs is illustrated in Figure 1, and the subsequent sections go into further depth about each of these approaches.

2.1. Local islanding detection approaches

Islanding detection (ID) at the DG site is achieved by measuring system settings using local approaches. Among the measured metrics are phase angle (PA), active power (AP), reactive power (RP), impedance, harmonic distortion (HD), and voltage. The following describes the three local/intelligent/active (LIA) categories: passive, active, and hybrid strategies. The passive islanding detection approaches (PIDAs) include over/under voltage (OUV), over/under frequency (OUF), rate of change of voltage (RCV), rate of change of frequency (RCF), rate of change of frequency over output power (RCFOP), rate of change of output power (RCOP), voltage unbalance approach (VUA), voltage phase jump detection (VPJD), harmonic content detection (HCD), wavelet transform (WT) approach, and Fourier transform (FT) approach, which are considered in this study. Similarly, the active islanding detection approaches (AIDAs) include active and reactive power variations, harmonic component injection (HCI), phase-locked loop phase perturbation (PLL-PP), active impedance detection (AID), frequency jump approach (FJA), active frequency drift (AFD), Sandia frequency shift (SFS), Sandia voltage shift (SVS), and sliding mode frequency shift (SMFS), which are considered in this review. The hybrid islanding detection approaches (HIDAs) include voltage fluctuation injection (VFI), RCV and AP shift, VUA and Sandia frequency shift (SFS), hybrid SFS and reactive power–frequency (Q–F) approach, and rate of change of reactive power (RCRP) and load-connecting approaches.

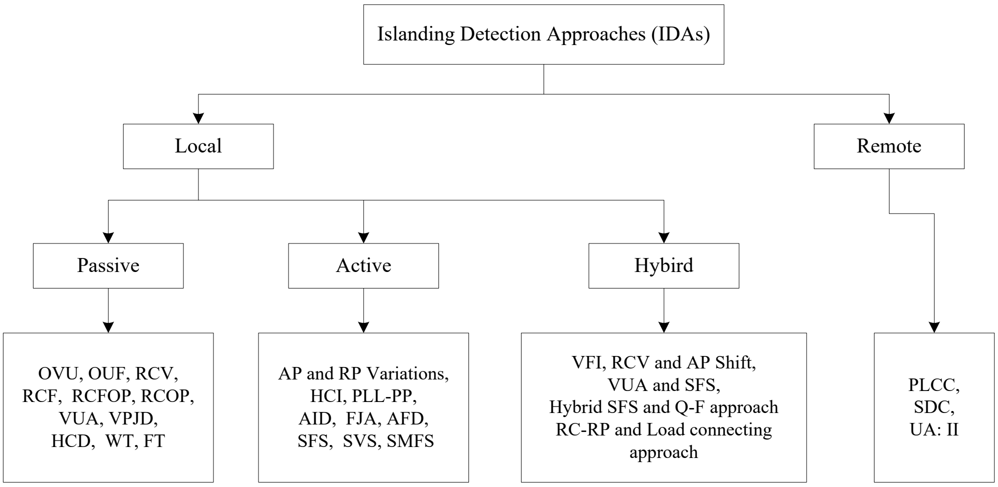

Figure 1. Classification of IDAs

2.1.1. Passive islanding detection approaches

Passive islanding detection approaches (PIDAs) track microgrid metrics, including harmonics, voltage, and frequency, and compare them to pre-established threshold values to find the islanding issue. The PIDAs capitalize on the fact that several of its parameters change significantly once the microgrid disconnects from the grid's utility. Figure 2 depicts the general structure for the deployment of PIDAs. They are widely recognized and employed since PIDAs do not produce interruptions like RP changes or HD that might decrease the power quality. They are also quite affordable. However, PIDAs do have a greater NDZ, and choosing the threshold calls for extra thought due to their high error detection rate (EDR). The following section provides the premise behind popular passive approaches and discusses their benefits and drawbacks.

a. OUV and OUF: This technique entails regularly checking the microgrids point of common couplings (PCCs) frequency (F) and voltage (V) to determine whether they fall within the earlier established limits. These magnitudes, enforced by the utility grid when a microgrid is attached, are relatively predictable under usual circumstances. The discrepancy between local production and demand that results in islanding causes V and F variations that vary from stated norms. This approach has the advantages of minimal cost and no impact on power quality. However, power and F variances may be insignificant if there is a modest mismatch between local production and the use of islanding. As a result, an NDZ exists where islanding is not identified [15]–[17].
b. RCV/RCF/RCFOP: RCV and RCF involve continuously monitoring the V and F variation rates at the PCC. To prevent false positives or identify islanding as a common grid interruption that falls within the permissible range as specified by the grid values, threshold values must be selected. The RCV/RCF approach is more sensitive, extremely dependable, and has a short detection time compared to OUV/OUF [18], [19]. A variant of this technique known as RCFOP measures the generators' F and output power and uses the quotient to identify islanding. It works particularly well in small workloads with few variations of load. It is a short NDZ, approximately 100 ms detecting time (DT), and extremely poor EDR [20], [21].
c. RCOP: This technique involves monitoring the PCC's AP and RP output. The RCOP assumes islanding occurs when the variation rate exceeds a particular threshold. However, it can produce superior outcomes than alternatives like RCV. RCOP approach has a smaller NDZ, is faster, and performs well with imbalanced loads. On the other hand, it has a highly high EDR, and the detection speed remains unaffected by the power imbalance between the load and distributed generation (DG) modules [22], [23].
d. VUA: The method entails observing the voltage imbalance across the three-phase output power of the microgrid (VU = NS/PS). Where PS and NS are the positive and negative sequence elements, VUA's underlying concept states that loading circumstances lead to variations in the VU triggered by HD maxima, with a high NDZ and a low EDR, the DT is roughly 53 ms [24], [25].

e. VPJD: This approach uses a PLL to determine this PA to determine islanding. Although the VPJD approach is simple, threshold levels must be appropriately determined since massive loads may generate fluctuations of this size when they begin. The local load determines efficiency; when the power quality is near unity, islanding cannot be identified since the phase jump will be insignificant [26], [27].
f. HCD: In the HD approach, islanding is detected by comparing the total harmonic distortion (THD) measured at the PCC with a specified THD threshold. When the microgrid is operating in a grid-connected condition, the inverter and the load produce relatively few harmonics, and the PCC voltage is a regular sine wave. However, the inverter's distortions will cause the PCC voltage to be distorted while in the islanding type of execution, making islanding detectable [28]. This technique has a 45 ms DT and works well for several DGs interconnected to a single PCC. It is straightforward to build. Setting the threshold is challenging because grid interruption might result in inaccurate EDR, and big quality factor Q and significant NDZ demands could avoid islanding from being detected [29].
g. WT approach: WT is conceptualized as a signal projected into a wavelet set of basic functions. This method can measure this magnitude within a specific frequency band since power changes Additionally, it can handle signals at various frequencies and timings [30]. Finding the high-frequency components that PV inverters supply is the foundation of the WT technique. The detection time (DT) spans from 17.19 to 26.87 ms, the NDZ is small, and it is immune to variations in grid voltage and frequency [31].
h. FT approach: While FT is a highly useful technique for examining stationary signals, it is not as good in analyzing non-stationary signals, changes, or transitory intervals. As a result, waveforms that fluctuate as a result of islanding cannot be analyzed using FT, even if it can be used to examine the amount of harmonics in stationary mode. FT-based methods have a high computational cost despite being fast and efficient [32], [33]. Table 1 gives the summary of the passive IDAs.

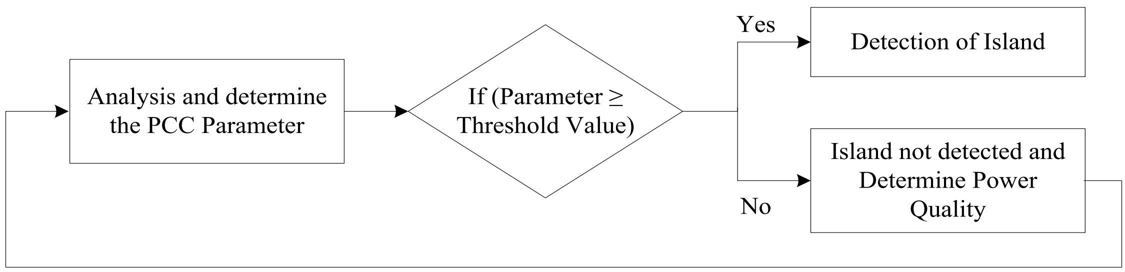

Figure 2. The basic structure of PIDA

Table 1. Summary of Passive IDAs

Passive IDAs	Power Quality Impact	NDZ	DT	EDR	Multiple Inverters	Performance
OVU/OVF	No	Large	4 ms-2 s	Less	Yes	Low
RCV/RCF/RCFOP	No	Small	24/24/100 ms	Higher	Yes	Good
RFOP	No	Small	24-26 ms	Higher	Yes	Low; only if balanced loads will not compensate for the change of load
VUA	No	Large	53 ms	Less	Yes	Good
VPJD	No	Large	10-20 ms	Less	Yes	Good; only when power merit close to 1
HCD	No	Large (For higher Q)	45 ms	Higher	Yes	Good, but fails at higher Q
WT	No	Very small	Up to 20 ms	NA	Yes	Higher only when DG units are connected to PCC through Inverters
FT	No	NA	Up to 1 ms	NA	Yes	High; Cost is more

2.1.2. Active islanding detection approaches

The perturbation and monitoring principle underpins the effectiveness of active islanding detection approaches (AIDAs). These techniques cause disturbances to the harmonics, frequency, current, and voltages of the system. The magnitude of the fluctuation at the PCC is minimal when a rigid grid is present because the grid variables take center stage. However, introducing a perturbation at the PCC causes a notable change in the DG properties as part of the islanding occurrences. The fundamental functioning of AIDAs is illustrated in Figure 3. The NDZ and EDRs of AIDAs are lower than those of PIDAs. To introduce disturbances, more electrical devices are needed because AIDAs degrade the power quality. Longer DT is needed to notice the impact of disruption, which may compromise the system's reliability. Also, the majority of AIDAs were created for DG units with inverters; they do not work with synchronous power plants. Here are descriptions of a few of the most well-known AIDAs.

a. AP and RP variations: This approach detects islanding by adjusting the power of the injected inverter while monitoring the frequency and amplitude variations in the voltage [34]. During islanding, the AP generated in the DG units will evaporate in the loads; therefore, for the AP in the DG and the loads to be equal, the V variation must satisfy V2/R. When the V variation above the OUV threshold, islanding is detected. When the F varies above a specific level, islanding is detected, just like the RP disturbance does. This technique has a modest NDZ and a DT between 0.3 and 0.75 seconds. It is also straightforward to use. Additionally, the approach might not be successful when several inverters operate simultaneously [35].
b. HCI: Several names exist for this technique: high-frequency signal injections, harmonic amplitude jump, or impedance at a particular frequency. The NDZ has decreased, DT is short (a few ms), and the EDR is poor for the majority of frequent implementations of the HCI method. However, the HCI approach results in a minor loss of power quality, raising the signal's THD [36], [37].
c. PLL-PP: By injecting a second harmonic interruption pulse at the PLL reference, this approach drastically alters the inverter current pulse reference. A disturbance's magnitude at the PCC is contingent upon the impedance linked to this location. Since the utility grid stabilizes the electrical voltage, there is no apparent effect on the produced current when it is grid-connected. However, once a second harmonic is introduced, the electrical voltage at the PCC will vary, making it possible to identify islanding when the grid is inaccessible. With a DT of about 120 ms, it boasts a tiny NDZ and a low EDR. It is also compatible with the parallel operation of several local power plants [38].
d. AID approach: With this technique, a disturbance in a voltage is caused by a disturbance in the electrical current or the reverse. It also disrupts the electricity system. While this approach typically results in a smaller NDZ, it is less effective when several localized inverters exist. The negative sequence currents (NSC's) disruption pulse is injected into the PCC via the NSC injecting method. The electric grid will receive this negative sequence whenever a grid-connected. But it will flow to the load once it has arrived, throwing off the voltage balance. Islanding will be identified if this imbalance is more significant than a specific value. Employing a periodic signal as the NSC reference signal enhances efficiency and sensitivity to noise while minimizing the NDZ [39], [40].
e. AFD: When inverter current is introduced through the PCC, an AFD partially modifies the waveform. Voltage, as well as frequency in the grid-connected state, are steady and governed by the grid. When islanding occurs, the injected current waveform deforms, causing the voltage to zero cross earlier than expected. Unless the OUF limit for recognizing islanding is exceeded by the voltage frequency monitored at the PCC, the inverter current (output) frequency will keep drifting. AFD's narrow NDZ and short detection time (less than two seconds) make it a simple solution to use [41], [42].
f. FJA: Since FJA additionally creates dead regions within the present waves, it is an altered type of AFD. Dead regions are added to FJA cycles every three, as opposed to AFD cycles wherein they are added to each cycle. Even though the inverter's current is deformed, its voltage wave at the PCC in the grid-connected state is undistorted. A voltage frequency fluctuation that occurs during islanding will be utilized to identify islanding. Similar to AFD, this method might not be able to detect islanding when multiple inverters are running at the same time [43].
g. SFS: Similar to AFD, SFS operates by introducing a disturbance to the inverter's voltage frequency while providing positive feedback. Even though the approach tries to alter the PCC's voltage frequency, the grid maintains it when the PCC is in a grid-connected state. Conversely, during islanding, the PCC's off-grid frequency increases along with the inverter's frequency. The process is repeated until islanding is found. With a detection time of 0.5 seconds, this method has the smallest NDZ when compared to the other AIDAs [44], [45].
h. SVS: The SVS and SFS work on the same principle, which is utilizing positive feedback to change the output power and current of the inverter and adjust the voltage magnitude of the PCC. The PCC's voltage magnitude is unaffected by power changes in the grid-connected state. Still, it is affected by power changes in island mode, making identifying islanding possible. SVS is simple to operate and has two drawbacks: it somewhat reduces power quality, and the resulting power change may decrease the inverter's performance [46], [47].
i. SMFS: It uses positive feedback to alter the PCC's voltage phase while focusing on the F variation to identify islanding. The load's PA and F will fluctuate while islanding activity; if the change in F is more than the limit, islanding can be identified. The SMFS approach has the benefits of being simple to use, having a lesser NDZ with a DT of roughly 0.4 seconds, and being very successful with various inverter setups. However, this approach affects the system's stability during transients and lowers power quality [48], [49]. The summary of the Active IDAs is tabulated in Table 2.

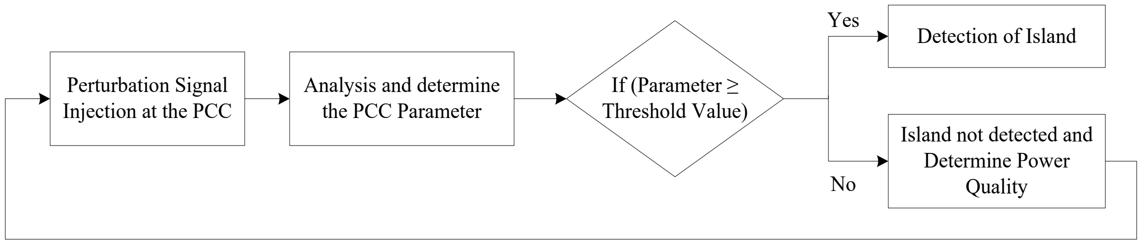

Figure 3. The basic structure of AIDA

Table 2. Summary of the Active IDAs

Active IDAs	Power quality impact	NDZ	DT	EDR	Multiple inverters	Performance
AP and RP Variations	Degrades	Small	0.3 - 0.75 s	Less	Yes	Instability issues occur when the DG unit injects additional AP/RP into the grid.
HCI	Degrades (Slightly)	Very small	few ms	Less	Yes	Good
PLL-PP	Degrades (Negligible)	Small	120 ms	Less	Yes	Good
AID	Degrades	Small	0.75-0.95 ms	Less	No	Good
AFD	Degrades	Large (for higher Q)	2 s	Higher	Yes	Good for resistive loads
FJA	Degrades	Small	75 ms	Less	Yes; performance reduction	Lower; when multiple inverters are synchronized
SFS	Degrades (Slightly)	Small	0.5 - 1 s	Less	Yes	Good
SVS	Degrades (Slightly)	Small	0.5 s	Less	Yes; performance reduction and DT are higher	Good; when the positive feedback approach uses
SMFS	Degrades	Small	0.4 ms	Less	Yes	Lower; when load phase > frequency deviation slope

2.1.3. Hybrid islanding detection approaches

Passive and active IDAs offer HIDAs, which are applied in two stages. The initial stage makes use of a PIDA, mainly for islanding detection. An AIDA is used to precisely identify islanding if it is detected in the first stage. The flow chart for the hybrid islanding detection method is shown in Figure 4. When PIDA and AIDA are combined, the efficiency metrics will increase; they typically exhibit a small NDZ and minimal power quality loss. However, the system is expensive, and the process takes a long DT, so its execution is not viable. Below is an overview of a few of the HIDAs that have been covered in the available literature.

a. VFI: Detecting islanding involves combining RCV and RCF in this VFI approach. To determine whether islanding may happen, the PCC monitors both the RCV and RCF. If either of these rates is above a certain threshold, action is taken [50]. For approval, a high-impedance load that switches on and off repeatedly is applied in the second stage, which causes a voltage fluctuation. Islanding is detected by monitoring the PCC voltage throughout the islanding procedure to see whether the periodic fluctuation affects the voltage [51]. Massive DG systems may find this approach less effective, as it is not dependent on quality variables and have a DT of less than 0.216 s.
b. RCV and AP shift: This is accomplished by integrating the AP approach fluctuation with the RCV. First, the mean RCV across five cycles is computed to look for evidence of islanding. The second approach adds more AP to the system to verify whether islanding has occurred if the computed voltage is higher than the set threshold level. The additional AP during the microgrid islanding activity will cause the PCC's voltage magnitude to rise. Consequently, islanding can be found by monitoring the PCC voltage and using a DT of less than 0.5 seconds. When RP is introduced, the PCC frequency rises, and if this frequency variation is above an established limit, islanding can be identified [52], [53].
c. VUA and SFS: The VUA and SFS are combined to make this task possible. The initial step in this procedure is to calculate the average VU due to changes in the system and the load. Suppose the detected VU is more than 35% of the average VU. In that case, the second step uses a positive feedback-based mechanism to drop the SFS progressively, from 60 to 59 Hz in one second, to distinguish whether the VU has been triggered by islanding or system fluctuation [54]. The voltage change was not caused by islanding if the nominal frequency remained at the PCC. However, if the frequency drops below 59.2 Hz in the next 1.5 seconds, islanding will be identified. This VUA with the SFS technique is most effective in microgrids where the penetration of non-synchronous power plants is modest, with a DT of 0.15–0.21 s.

d. Hybrid SFS and Q-F approach: This approach adds a Q-F droop curve to the SFS approach to modify it and minimize the NDZ while keeping the ideal gain (K) constant [55]. The load's quality factor determines the appropriate gain (K); if the quality factor is greater than 5, the gain (K) will be too high to produce a false positive and may potentially lead to system instabilities. This approach has a 1.4 s DT and observes this frequency's fluctuation for islanding [55], [56].
e. RCRP and load-connecting approach: The method for detecting islanding involves merging the RCRP with the load link. In the first step, the monitored change in RP exceeds the predetermined threshold. In the second stage, an appropriate load is connected to the microgrid to vary the RP; however, for any alteration in load while islanding activity RCRP, the additional connected demand is used to identify islanding. This technique has a 40 ms DT and can identify islanding even with slight load fluctuation. The drawback of this approach is that it is difficult to determine the right additional load [57], [58]. The summary of the hybrid IDAs is tabulated in Table 3.

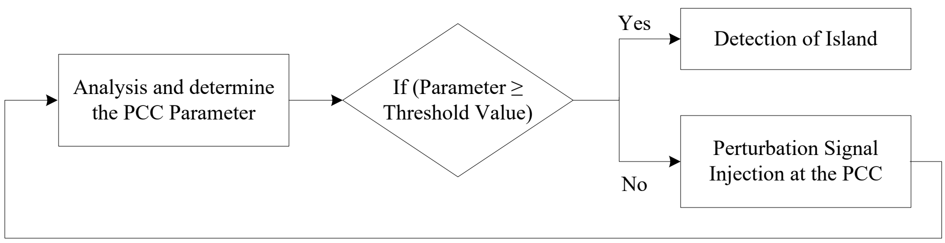

Figure 4. The basic structure of HIDA

Table 3. Summary of the hybrid IDAs

Hybrid IDAs	Power quality impact	NDZ	DT	EDR	Multiple inverters	Performance
VFI	Degrades; Only when voltage fluctuates	Small	0.2 s	Less	NA	Good
RCV and AP shift	Slightly; Only when AP triggers	Small	0.5 s	Less	Yes	Same as AP and RP variations
VUA and SFS	Slightly; Only when SFS triggers	Small	0.15-0.21 s	Less	Yes	Good
Hybrid SFS and Q-F Approach	Degrades; Less than SFS	Higher than SFS	1.4 s	less than SFS	NA	Higher than SFS
RCRP and load-connecting approach	Degrades (Slightly); When using the Load-Connecting Approach	Small	40 ms	NA	Yes	Good

2.2. Remote islanding detection approaches

Remote islanding detection approaches (RIDAs) use sophisticated signal analysis and communication networks to detect islanding. RIDAs are particularly good for islanding detection since they do not have an NDZ, EDR can be removed, and they do not impact power quality. RIDAs are highly advantageous for extensive microgrid usage, even if they are typically costly to adopt for small microgrids. Here's a discussion of a few of the remote techniques like communication approaches (power line carrier communication (PLCC), standard data communication (SDC)) and utility approach-impedance insertion (UA-II) as mentioned in the literature.

a. PLCC: The DG and grid sides are where the transmitters (TXs) and receivers (RXs) are placed in the PLCC approach. When a communication signal is disrupted, it signifies that islanding has occurred [59]. TXs generate this type of signal in addition to the power connection. The PLCC approach can identify islanding if the signal is lost for 3 consecutive periods throughout its four-cycle signal duration. This approach has been shown to function on numerous inverter systems, has a 200 ms DT, has no NDZ, and has no effect on power quality. However, this strategy is not viable for low-volume DG systems because of the expensive TX set at the grid side [60]
b. SDC: This group includes numerous strategies, including creating a separate communication channel between the utility grid and the microgrid. A widely used technique known as signal produced by disconnect (SPD) involves sending a signal exclusively when the electric grid is cut off. A supervisory control and data acquisition system (SCADA) is the foundation of specific additional methods of communication and enables remote power plant monitoring of status [61]. An intricate and costly transfer trip approach [62] can also serve as the foundation for communication techniques.

c. UA-II: This technique involves adding a lower-value impedance to the grid side, typically a series of capacitors. This part's breakers are typically accessible; they close only if an islanding situation arises [63]. The microgrid can immediately identify the unexpected change in RP consumption resulting from this. The summary of the remote IDAs is tabulated in Table 4.

Table 4. Summary of the remote IDAs

Remote IDAs	Power quality impact	NDZ	DT	EDR	Multiple inverters	Performance
PLCC	No	Small	Very Few ms	NA	Yes	Higher
SDC	No	Small	Very Few ms	NA	Yes	Higher
UI-II	No	Very small	Few ms	Less	Yes	Higher

3. RESEARCH GAPS AND FUTURE SUGGESTIONS

This section highlights the merits, demerits, research gaps, and future suggestions of IDAs. The merits and demerits of the remote and local IDAs are addressed below: Remote IDAs, which have zero NDZ and low DT, provide higher reliability. Their influence on power quality is minimal. On the other hand, remote IDAs have more significant execution costs and complexity. Passive IDAs are more straightforward and beneficial due to their low cost as well as short DT power quality issues. However, they are more vulnerable to threshold settings and deal with larger NDZ, which impacts reliability problems.

On the other hand, the active IDAs have a higher DT and less NDZ and EDR, but they have a more significant impact on power quality because of inject perturbations. Compared to passive IDAs, active IDAs have a modest execution cost and complexity. Hybrid IDAs have very short DTs and provide perturbation only in cases where an islanding issue is anticipated. Nevertheless, their implementation is more complex and costly. Although previous researchers thoroughly addressed islanding difficulties, numerous restrictions remain. The following are some of the research gaps that recent review works have highlighted:

a. Larger NDZs in passive IDAs: To address the issues with large NDZs and the system's difficulty functioning in passive IDAs with a negligible or zero power imbalance, these modern techniques enhance the system's accuracy and effectiveness while mitigating the issue of larger NDZs.
b. Less emphasis on IDAs for DC networks: The DC network has many problems, including the detection of islanding. Several investigations on IDAs are ongoing for AC networks, but until recently, there was little literature on the islanding issue for DC networks.
c. An issue with noisy metrics: Real power system statistics have a noisy information set, yet specific approaches do not effectively handle this issue.
d. Using contemporary IDAs: To solve the islanding detection problem, contemporary IDAs such as signal processing and artificial intelligence-based strategies are being used. These techniques can handle complex nonlinear system challenges.
e. Common issues: Most of the existing approaches (remote, active and hybrid) incur high execution costs due to the usage of expensive devices. Few of the passive IDAs are not so accurate during usage in small-scale networks than other IDAs. Additionally, few IDAs caused problems with power quality and a heavy computing load on the machine.

Even though IDAs have been studied for over three decades, there are still many avenues for future research. Research into the combinations that collaborate with various IDAs could be pursued to develop novel hybrid approaches. Combinations with insight can lower the NDZ, lower the EDR, and raise the DT. The future direction of the IDAs is listed as follows:

a. Since passive IDAs are low-cost, more significant development, despite difficulties, is anticipated. Because the converter itself serves as the source of harmonic information about the frequency of switching harmonics, using passive IDAs becomes more practical.
b. While active IDAs introduce tiny fluctuations in a steady state, they help detect islanding. However, preventing the steady-state loss of power quality will remain a challenge for active IDAs.
c. From an economic perspective, research should concentrate on low-cost methods that can eradicate NDZ to overcome limitations. Additional studies on IDAs will primarily focus on improving the speed and precision of identification.
d. While IDAs may require more software and hardware capabilities, learning algorithms and sophisticated digital signal processing (DSP) approaches are promising tools for islanding identification and will be further improved.

4. CONCLUSION

The article presents an extensive assessment of different IDAs. IDAs can be broadly divided into two categories: local and remote. Remote IDAs are quick, dependable, and efficient with no NDZs; they operate by using signals for communication to connect the microgrid to the central grid. These methods are sophisticated and costly, yet they may be used with multi-inverter microgrids and do not reduce the power quality. Local approaches fall into three categories: hybrid, active, and passive. Passive IDAs are recommended because it is simple and affordable to use in real-world situations. Active IDAs introduce a perturbation into the system that impacts the quality of the power. While hybrid IDAs include passive and active approaches. The necessity for additional gadgets in active and hybrid IDAs to introduce the perturbation increases the difficulty and cost of execution. In contrast to local IDAs, signal processing-based IDAs have recently drawn greater interest for their ability to accurately and efficiently detect islanding conditions in the shortest time while maintaining power quality. The statistical evaluation of the IDAs' effectiveness based on NDZ, power quality impact, DT, and EDR was explored. Finally, highlight the gaps in the research and suggest further investigation.

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DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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BIOGRAPHIES OF AUTHORS

Resna S. R. is a research scholar and faculty member of engineering at The Oxford College of Engineering, Bangalore. She obtained her B.Tech. degree in electrical and electronics engineering in 2005 from CUIET, Calicut University, Kerala, and her M.Tech. degree in power electronics from Amrita Viswavidyapeetham University, Coimbatore. She has nine years of academic teaching experience and has worked for both the NBA and NAAC. Her areas of interest are power systems, power electronics, and electrical machines. She can be contacted at email: resnatoce@gmail.com.

Devi Vighneshwari B. is working as professor and head of the department in the Electrical and Electronics Engineering Department of The Oxford College of Engineering, Bangalore. She completed her B.E. in electrical and electronics engineering in 2001, M.E. in power systems in 2002, and Ph.D. in 2020 from Annamalai University, Chidambaram, Tamil Nadu, India. She has 19 years of teaching experience and has published various papers in international journals and conferences. Her areas of research interest are power quality, smart grid, microcontrollers, power systems, and internet of things. She can be contacted at email: devioxford@gmail.com.