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# A Comprehensive Review of Islanding Detection Methods for Distribution Systems

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***Abstract* — The rapid increasing of Distributed Generators (DGs) in electric power system necessitate updating of the grid interconnection requirements, particularly with penetration of microgrids (MGs), which accelerate the transforming to decentralization of the networks. Accordingly, the fast detection of an unintentional islanding has a key role in the future energy scenarios, both for the DGs that operate in grid-connected mode and for the MGs with a reliable facility for transition into the island mode. This paper introduces a modified classification for islanding detection methods in literature, which categories them into single inverter-based, multi inverter-based, AC microgrid and DC microgrid. Also, the performance of inverter-based (single & multi) under a wide range of existing islanding detection methods (IDMs) is evaluated along with their advantages/disadvantages and considering which of them are able to work with AC MGs. Furthermore, IDMs for DC MGs are discussed.**

***Index Terms*—Islanding Detection (ID), Under/Over Frequency (UOF), Under/Over Voltage (UOV), Non-Detection Zone (NDZ).**

## I. Introduction

NATIONAL GRID (NG) in the UK has an ambition to facilitate the electrical energy for sustainability transition toward the net zero 2050 [1], [2]. To meet this strategy and for the delivery of secure, reliable and affordable energy for all consumers [2], particularly with power system developing toward power electronic-based systems [3], the grid connection code has recently been updated. Therefore, the islanding detection is one of the major subjects which has been taken into account in national grid codes and international standards. In accordance with BS EN 62116:2014 [5], islanding is a condition in which a part of system, containing load and generation, is isolated of the network. Also islanding is divided within intentional and unintentional status [5], which the latter is the main concern of utilities. Fig. 1 illustrates a simple local network after the grid disconnection. In an unintentional islanding, as the utility does not have any control on distributed generator (DG) and load, it may cause a hazard for utility line-workers or public and damaging to DGs particularly when the DG is reconnected. Accordingly, a secure and reliable detection for an unintentional islanding is one of the essential targets of the engineering recommendation [4].

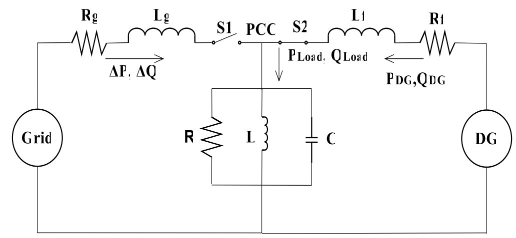


Fig. 1. Islanding System with DG and load after the grid disconnection

To achieve this, a DG must be equipped by a protection to disconnect it from the load in the loss of one or more phases of the network [4]. The common name for this type of protection is Loss of Mains (LoMs) protection, which is required to disconnect the DGs, to ensure that the customers are not supplied with voltage and frequencies outside statutory limits [4]. However, it might not be precisely compatible with the performance of the microgrids, thus the existing IDMs are not able to cover the operation in AC and DC microgrids. This paper is organized in six sections. Section II discuses several international standards to highlight islanding detection parameters. In Section III, the main parameters of islanding conditions are explained. Section IV presents a comprehensive review of wide range of IDMs classification for inverter-based (single & multi). Section V considers which one of IDMs have an acceptable performance for AC MGs. Finally, IDMs for DC MGs are discussed in Section VI.

## II. International Standards – Islanding Detection

General speaking, the basic principal of islanding detection for the DG grid connected in most of international standards are similar. All of them consider the same parameters for islanding detection such as detection time, quality-factor, and voltage/frequency thresholds. However, the quantity of the aforementioned parameters might be different. Unfortunately, the lack of adaption the different standards leads to expensive inverter based implementation. Thus, costs for inverters and DGs equipment are higher than they expect [9]. Table I has listed the main parameters for some of the standards, [5]-[8].

Table I
Anti-Islanding and Corresponding International Standards

| Standards | Network Frequency | Qf | ID time | Frequency Threshold | Voltage Threshold |
|---|---|---|---|---|---|
| IEEE1547.1 | 60 Hz | 1 | ≤ 2s | 59.3-60.5Hz | 0.88-1.1pu |
| IEEE929 (2000) | 60 Hz | 2.5 | ≤ 2s | 59.3-60.5Hz | 0.88-1.1pu |
| BS EN 62116 | 50 Hz | 1 | ≤ 2s | 48.5-51.5Hz | 0.85-1.15pu |

| | | | | | |
|---|---|---|---|---|---|
| BS EN 50160 | 50 Hz | 1 | ≤ 2s | 49-51Hz | 0.9-1.1pu |

## III. MAIN CRITERIA/PARAMETERS IN THE ISLANDING MODE

The main equations for evaluation an islanding conditions are presented as below [10]-[14]:

$$f_{res} = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

$$Q_f = R\sqrt{C/L} \quad (2)$$

$$\left(\frac{V}{V_{max}}\right)^2 - 1 \le \frac{\Delta P}{P} \le \left(\frac{V}{V_{min}}\right)^2 - 1 \quad (3)$$

$$Q_f.\left(1-\left(\frac{f}{f_{min}}\right)^2\right) \le \frac{\Delta Q}{P} \le Q_f.\left(1-\left(\frac{f}{f_{max}}\right)^2\right) \quad (4)$$

Where: $f_{res}$ (Hz) is the resonance frequency at the point of common coupling (PCC). $Q_f$ is the quality factor. R, L and C are the resistance (Ω), inductance (H) and capacitance (F) respectively as a parallel RLC load. $V_{max}, V_{min}, f_{max}, f_{min}$ are permisible limits of voltage and frequency. P (MW) is the rated active power of DG. $\Delta P = P_{Load} - P_{DG}$ & $\Delta Q = Q_{Load} - Q_{DG}$ are active/reactive power mismatch.

## IV. CLASSIFICATION OF ISLANDING DETECTION METHODS

There is a broad range of IDMs presented in literature, however, none of them is able to be economical satisfied the entire network requirement at the same time. In addition, the consensus for an IDM becomes weaker with increasing the number of power electronics based DG in single-based inverter operation or multi-based operation. On the other hand, the penetration of AC and DC microgrids in the distribution network is increasing [15], [16], thus their operation under IDMs have to be evaluated and updated [69], [70]. Therefore, a modification in IDM's category is illustrated in Fig. 2. Many papers have reviewed the IDMs as [17]-[35], however, only few of them have considered the ID for microgrids operation. In the following sections, a wide range of existing IDMs along with their advantages and disadvantages for inverter-based (single & multi) are discussed.

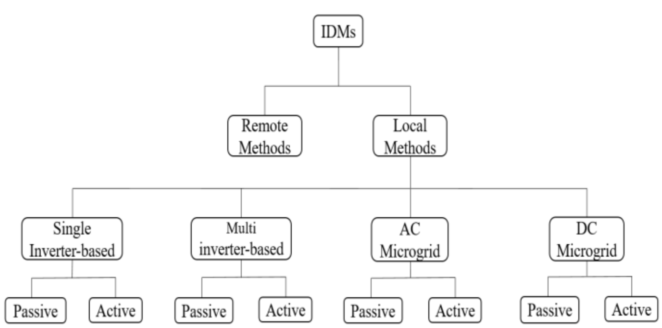


Fig. 2. Classification of IDMs in the literature.

### *A. Remote Methods*

The remote methods are based on the communication between the grid and any type of system including inverter-based (single & multi), AC and DC microgrids. The main advantages of the remote method is its zero NDZ [33] and its independency from the type of DGs [9], therefore they can work with all of four main categories. With developing of the smart grid, the increasing of communication layers in power system are expected, therefore the new islanding detection schemes with a communications-based and the smart grid devices is more interested [24]. However, communication-based methods necessitate the involvement of utility companies in implementation of islanding detection schemes, which could be the major obstacle [22]. Fig. 3 and Table II show the main types of remote methods.

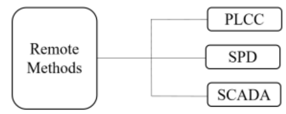


Fig. 3. Remote Methods.

### *B. Local Methods*

Local islanding detection methods often are based on the local voltage and current signals at the PCC [9]. They can be further divided into two sub-types: passive and active methods. In the next sections many active and passsive methods are discussed.

#### *i. Passive Methods*

Passive detection methods monitor the electrical parameters mostly voltage and frequency at the PCC and compare them with their pre-set threshold values. If the measured parameters at the PCC are beyond their threshold, the islanding is detected, otherwise, it is within non-detection zone (NDZ). Fig. 4 and Table III show the common classical passive methods with their advantages and disadvantages, which are applicable for inverter-based (single & multi). Recently, signal processing (SP) based IDM techniques have been used for islanding detection. They are competitive with active methods because of their negligible influence on power quality with a small NDZ [32]. However, in SP techniques the selection of threshold value is quite difficult task particularly, when the value is set high, which unable to detect the islanding [42]. Fig. 5 and Table IV show the most common of them for inverter based (single & multi).

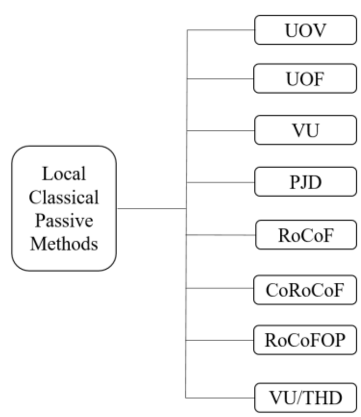


Fig. 4. Local Classical Passive Methods.

Table III
IDM - Local Classical Passive Methods

| No. | Reference | Method Name | Abbrev. | Description | Detection time | Advantage | Disadvantage |
|---|---|---|---|---|---|---|---|
| 1 | [13], [18], [5] | Under/Over Voltage | UOV | ΔP≠0 or ΔQ≠0→ ΔV≠0 | ≤ 2s | Simple & low cost | NDZ≠0 |
| 2 | [13], [18], [5] | Under Over frequency | UOF | ΔQ≠0 → Δf≠0 | ≤ 1s | | |
| 3 | [21], [36] | Voltage Unbalance | VU | Measurement: VU=V-/V+ | 0.053s | | NDZ≠0, possibility of mal operation |
| 4 | [4], [13], [20] | Phase Jump Detection | PJD | Based on phase difference between voltage & current at PCC | ≤ 2s | Simple & low cost, without any effect on power quality | NDZ≠0, Not applicable in LoMs |
| 5 | [4], [37], [39] | Rate of change of frequency | RoCoF | Measurement: df/dt | ≤ 1s | Simple and fast detection | dependency on system inertia |
| 6 | [40] | Comparison of RoCoF | CoRoCoF | Compare df/dt of DG with the grid frequency | 0.6s | Able to discriminate between LoM & grid disturbance | Proper operation only with a high change in frequency |
| 7 | [41] | RoCoF over Power | RoCoFoP | Compare δf/δPL with pre-set threshold | 0.1s | Simple & low cost | NDZ≠0 |
| 8 | [20], [36] | VU/ Total Harmonic Distortion | VU/THD | A hybrid method to measure VU & THD variation of current | 0.129s | Simple and fast detection | With higher Qf it fails |

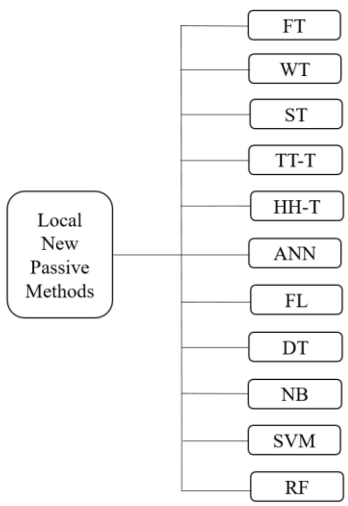


Fig. 5. Local New Passive Methods.

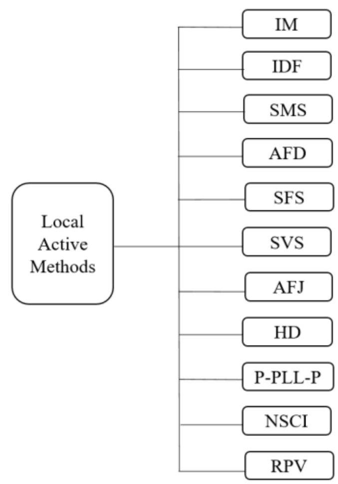


Fig. 6. Local Active Methods.

Table II
IDM - Remote Methods

| No. | Reference | Method Name | Abbrev. | Description | Detection time | Advantage | Disadvantage |
|---|---|---|---|---|---|---|---|
| 1 | [9], [17] | Power Line Carrier Communication | PLCC | The system is equipped with a signal generator & a signal detector for each DG | < 2s | NDZ=0, independent from the type of DG | Expensive, interference with other signals |
| 2 | [13] | Signal Produced by Disconnect | SPD | SPD uses a microwave link, telephone line or other means for communications | < 2s | | Expensive and complex in installations and operations |
| 3 | [9], [20], [22], [24] | Supervisory Control And Data Acquisition | SCADA | Based on monitoring the status of all circuit breakers that could island a DG | Might be more than 2s | | Expensive, detection might be slower than utilities standards |

### *ii. Active Methods*

Active methods inject disturbances into the supply to detect islanding based on system responses via the measured signal locally [9]. They have been employed for inverter-based (single & multi) in literature. They have a small or even zero NDZ with an acceptable islanding detection time. Despite of their advantages, they scarify the power quality. Fig. 6 and Table V show the most applicable methods.

## V. A Comparison of IDMs between Inverter-Based (Single and Multi) & AC Microgrids

The researchers have tested only few of the above mentioned local IDMs to evaluate the IDMs operation in AC microgrids. It has been confirmed that UOV, UOF, PJD, Voltage Harmonic (classical passive methods) and SVS, SFS, SMS, AFD (active methods) are not well performed in Ac microgrids [65]. Although, intelligent techniques as Table IV have more capability for operation with multi-inverer-based, but they have not been investigated in AC microgrid. Also, in [31], it was confirmed that a RoCoF measurement severely affects the small scale islanded microgrids, as it is very sensitive to minor changes. Therefore, even minor disturbance in island microgrids might lead to frequency instability or a total system blackout. In addition, in [30], it was shown that the injected harmonic for active method – HD, have negative impact on the power quality in island mode for AC MGs.

Table V
IDM - Local Active Methods

| No. | Reference | Method Name | Abbrev. | Description | Detection time | Advantage | Disadvantage |
|---|---|---|---|---|---|---|---|
| 1 | [13], [20], [51] | Impedance Measurement | IM | Local system impedance measurement | ≤ 12 cycle | Negligible NDZ, inexpensive | Poor results with multiple inverters |
| 2 | [13], [20], [52] | Impedance Detection at Specific frequency | IDF | Injection of current harmonic in a specific frequency into PCC | (0.04-0.06) s | Ability of islanding detection under different conditions | Nuisance trip in multiple inverter and NDZ≠0 |
| 3 | [19], [53], [54] | Slip Mode frequency Shift | SMS | Control of current & voltage as a function of frequency at PCC | 0.2s | Simple, effective with the multiple inverter | NDZ≠0, poor effectiveness for high Qf |
| 4 | [13], [54], [55] | Active Frequency Drift | AFD | A disturbance in the inverter's current makes a change in voltage zero crossing | ≤ 2s | | |
| 5 | [19], [20], [54], [56] | Sandia Frequency Shift | SFS | An extension of AFD which utilizes positive feedback to the frequency | ≤ 2s | Negligible NDZ, inexpensive | |
| 6 | [20], [54], [57] | Sandia Voltage Shift | SVS | Based a positive feedback to the amplitude of the voltage | ≤ 2s | Negligible NDZ, simple and inexpensive | Slight degradation of power quality |
| 7 | [13], [25], [58] | Active Frequency Jump | AFJ | A modification of AFD, and similar to impedance measurement. | ≤ 4.5 cycle | Less the power injected into the grid with a fast detection | Poor results with multiple inverters |
| 8 | [36], [59] | Harmonic distortion-based | HD | Voltage change in island, with three indices: (THD), (DF) & Harmonic Amplification Factor (HAF) | (0.016-0.24) s | Low cost with a fast detection | NDZ≠0 and needs more evaluation under higher Qf |
| 9 | [32], [60] | Phase PLL Perturbation | P-PLL-P | The Goertzel algorithm for the measure of the second harmonic | (0.103-0.104)s | No effect on the grid stability, similar result with any type of load, fast detection | It may influence on the PLL. |
| 10 | [25], [32], [62] | Negative-Sequence Current Injection | NSCI | Based on injecting a negative-sequence current through the VSC | ≤ 0.06s | Fast detection, insensitive to the load variations | It may cause an unbalance voltage at PCC |
| 11 | [19], [63], [64] | Reactive Power Variation | RPV | Based on the relation between the frequency and the reactive power. It (Q-f droop control) | ≤ 0.17s | Fast detection, simple, effective multi inverter | Poor effectiveness for the higher Qf |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | [42], [44] | Time – Time Transform | TT-T | Similar ST, but it includes 2-D time-time signal | to compare STD with threshold | Fast detection | Sensitivity to noise |
| 5 | [32], [42] | Hilbert Huang Transform | HH-T | Used for processing non-linear and non-stationary signals | ≤ 2 cycle | Simple, fast detection | It is not suitable for all application |
| 6 | [45] | Artificial Neural Network based | ANN | Processed designed based on the neuronal structure of the brain | 0.7s | Effective island detection | longer computational times for training |
| 7 | [33], [46] | Fuzzy logic (FL) | FL | Based on the data mining approach, with fuzzy classifier | ≤ 1 cycle | NDZ = 0, work with multi inverter | Complexity and dimensionality of classification problems |
| 8 | [33] [47] | Decision Tree based | DT | Based on a combination of (WPT) & (DWT) | 0.045s-0.050s | Fast detection | NDZ≠0 |
| 9 | [48] | Naive Bayesian classifier | NB | Based on Bayes' theorem. Based on the training set of data | NA | Simplicity, work with multi inverter | |
| 10 | [33], [49] | Support Vector Machine classifier | SVM | voltage & current measurement at PCC to use as inputs to the SVM | NA | no effect on power quality | complex, impractical for real system |
| 11 | [50] | Random forest classifier | RF | voltage & current measurement and sampling frequency of 1 kHz | single inverter: ≤ 0.37s multi inverter: ≤ 0.115s | Work with multi inverter | NDZ≠0 |

The aforementioned discussion confirms that the IDMs options become more limited for AC microgrids. Therefore, it is required to carry out more investigation, modelling and laboratory tests on the IDMs to improve performance for AC microgrids.

## VI. The IDMs for DC Microgrids

Many advantages for DC microgrids such as lower loss, greater controllability and enhanced power quality in compare with AC microgrids [66], [67] encourage the network operators and suppliers to move towards DC microgrids. For DC microgrids, too few of IDMs have been presented and it is still in the early stages. The proposed passive IDMs for DC microgrids are including:

- Rate of change of voltage (RoCoV) [34]
- Rate of change of current (RoCoC) [34]
- Frequency and voltage deviation at PCC [68]

The equation of RoCoV and RoCoC are as follows:

$$\mathrm{RoCoV} = \frac{V_{(n)} - V_{(n-\Delta n)}}{\Delta n} \quad (5), \qquad \mathrm{RoCoC} = \frac{I_{(n)} - I_{(n-\Delta n)}}{\Delta n} \quad (6)$$

Where, $V_{(n)}$ and $I_{(n)}$ are the magnitude of voltage and current at n$^{th}$ sample respectively and $\Delta n$ is the step size of the algorithm. During islanding, real power mismatch force a deviation in voltage and current. Thus, the magnitude of RoCoV and RoCoC will have a value for islanding detection. The results show that the abovementioned techniques are not able to provide a discrimination requirement between islanding and other non-islanding events. Frequency and Voltage deviation at PCC is another passive method for the DC microgrids based on the reaction of the DC voltage from microgrid owing to the frequency and voltage deviations of the AC grid side. This method needs a communication link for a real set up. Obviously, the studying of active ID methods for DC microgrids is required more research.

## VII. Conclusions

Most of IDMs has been reviewed. A modification for IDMs classification has been presented. It includes passive and active methods for single inverter-based, multi-inverter based, AC and DC microgrids. Many passive and active techniques have been evaluated and compared. The results show that passive methods have a rapid detection time, simple implementation but they have a large NDZ. Active methods have a negligible NDZ, however degrades the power quality, particularly with increasing the number of DGs.

Remote ID methods are flexible for operation with any structure type including inverter-based (single & multi), AC and DC microgrids with zero NDZ, although they require the communication channels that makes costly their installation. Also, they involve the utility companies in implementation of islanding detection scheme which is undesirable. In addition, this study shows that only a couple of the existing IDMs have been studied in detail for AC microgrids and more research is required to update the IDMs for a suitable performance. The options of islanding detection for DC microgrids is more limited as it is still in infancy.

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