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A Review on Loss of Mains and Islanding Detection in Microgrids with Multiple Renewable Energy Sources

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Abstract

The conventional distribution systems are radially configured and power flows unidirectionally from the transmission substation to the downstream loads. However, unlike the traditional system, power flows bi-directionally in the modern distribution systems which incorporate Renewable Energy Sources (RESs) as the grids evolve to smart grids. This modern system comes with inherent challenges in terms of system protection as the system loads receive power supply from multiple Distributed Generators (DGs) in the same microgrid (MG). The MG operation is a new concept for future energy distribution system that enables the RES to be integrated at points close to the load centres. This consists of a number of DGs that are usually interfaced to the grid either directly or through power inverters. For the islanding operation of multiple DGs in a MG, the main consideration is on how to maintain the voltage and frequency within the required standards and improve power supply reliability. This paper reviews and categorizes various approaches of loss of mains and islanding detections in MGs with multiple RES, compare them in terms of their respective advantages and disadvantages and also highlight how the various islanding detection methods have evolved over time. In addition to this, the future trends of these methods will be analyzed and discussed in detail as found in the research literature.

Keywords: Loss of mains detection, DGs, RES MGs, Islanding

1. INTRODUCTION

The use of RESs DGs is on the rise of recent due to a number of factors. These include; an effort to supply the increasing power demand in proportion to increasing population, the general response to the global warming and environmental concerns, as a result of privatization and deregulated electricity market, among others. Unlike the conventional distribution systems where power flows in one direction from the main substation into the downstream loads, the power flows in both ways in grids with high penetration of RESs connected at the distribution level and smart grids in general. This brings a challenge when it comes to the system protection coordination, islanding, safety, system stability, reliability, supply security and voltage regulation especially when there is multiple RESs of different technologies in the same MG [1] [2] [3].

Now that most of the RESs produces power intermittently, there is a consequent variation of system voltage and frequency within the MG. To overcome this challenge of intermittency in power production, various RESs like wind and photovoltaic (PV) are usually integrated in the same MG to form a hybrid system. This improves the reliability of power supply to some extent. This hybrid of RESs may be connected to the grid to share the excess or get the deficit power as the situation may arise [4]. In addition to this, most of the RES employ power electronic interfaces to convert the generated power into usable electrical energy before connection to the utility grid. However, these electronic converters introduces harmonics into the system.

This high penetration of RES in distribution systems has led to islanded operation mode of DG units and MGs as a suitable approach to maintain continuity and reliability of supply instead of disconnecting the DG when a fault occurs [5]. This is because the use of RES is an economical and preferred choice in remote areas where it is not economically feasible to construct transmission lines to reach those customers. It also assists in transmission loss reduction by having generation being close to load centres. Among the distributed generation sources, RESs are developing very fast because of favourable government policies that are geared towards reducing greenhouse gas emissions as per the international standards and also to reduce the consumption of fossil fuels which are limited in supply [6].

The operation of DG units in MGs can broadly be classified into two categories based on their configurations. That is, they can be configured to operate on the voltage-controlled mode or current controlled mode [7]. In grid-connected mode, the units are operated in the current controlled mode while in islanded condition the DGs operate in voltage and frequency control mode. The most adopted control strategies for current control mode and inverters are discussed in references [8] and [9]. In islanding mode, the electronic converter interfaces between the loads and the micro-source acting as voltage sources. These are responsible for the power sharing according to their ratings and availability of power from their corresponding energy sources or prime movers [10].

In order to maintain continuity of the power that is supplied to the loads, most utilities recommend islanded mode of operation for DG units in case of a contingency leading to loss of mains. To attain the required efficiency and reliability, the LOM detection methods should be fast, precise, and cost-effective. Hence, various methods of LOM detection and their corresponding control strategies have been developed and deployed on the RES units and MGs. In accordance to IEEE Standard 1547-2003, islanding should be detected as quickly as possible, within 2 seconds after it occurs, to be precise. Islanding operation can be defined as a condition whereby a part of the entire power system grid with loads and generators are isolated from the rest of the grid [11]. The necessary conditions for MG LOM and islanding are published and elaborated in standards such as IEEE-1547 [12] and IEC-62116 [13]. An islanding concept of typical topologies of MGs as suggested in IEEE 1547.4 [14] [15], is illustrated diagrammatically in figure 1 below.

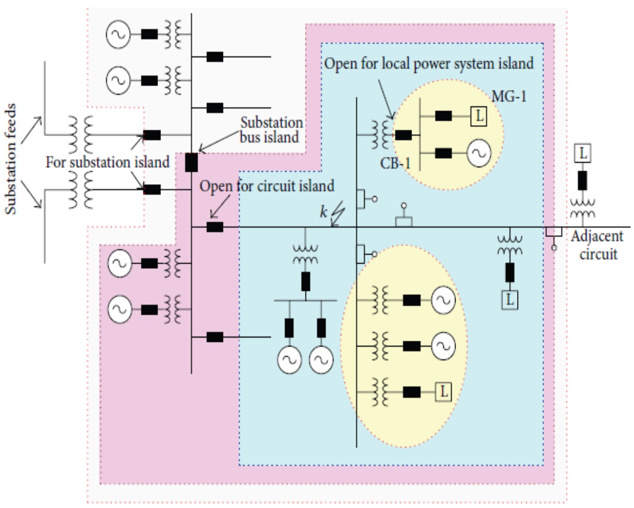

Figure 1: Illustration of Islanding Concept

The rest of this paper is organized as follows: In Section 2, the current standards and methods used for islanding detection are described. The technical considerations of islanding are presented in Section 3. Section 4 illustrates the performance criteria for islanding detection. Finally, the islanding detection considering multiple DGs in MGs and its future trends are discussed in Sections 5.

2. CURRENT STANDARDS AND METHODS USED FOR ISLANDING DETECTION

As of now, there is no specifically designed and standard method for testing the islanding detection and operation for MGs. Some of the existing methods make use of one DG technology only while others a combination of DG sources. Figure 2 below shows a generic system for islanding analysis as per IEEE1547 [11].

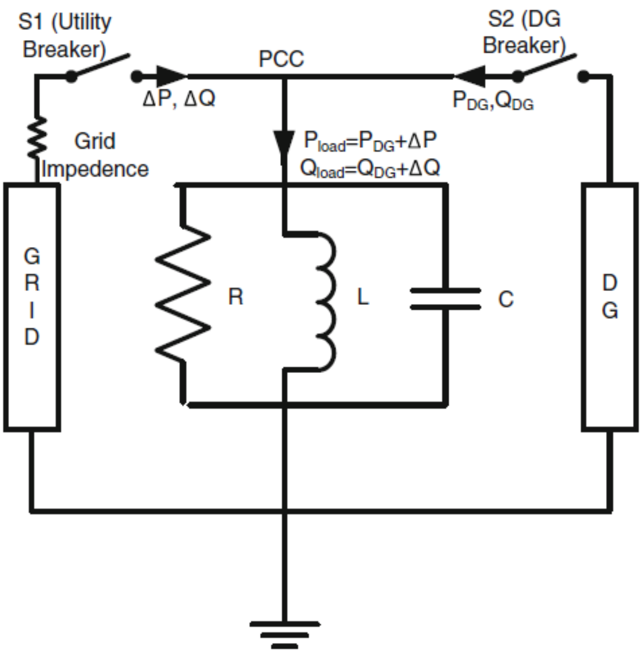

Figure 2: IEEE general system for islanding analysis

The RLC and frequency values can be determined by using the equations (1)-(4) below;

$$R = \frac{V^2}{P_{LOAD}} \tag{1}$$

$$L = \frac{V^2}{(2\pi * f * Q_f * P_{LOAD})} \tag{2}$$

$$C = Q_f * \frac{P_{LOAD}}{(2\pi * f * V^2)} \tag{3}$$

$$f = \frac{1}{\left(2\pi * \sqrt{L/C}\right)} \tag{4}$$

More often than not, Over/Under Voltage (OUV), Over/Under Frequency (OUF) and the Rate of Change of Frequency (ROCOF) at the PCC are often used as the most conventional islanding detection parameters. This is illustrated by the equations (5)-(9) below;

$$P = \frac{U_{PCC}^2}{R} \tag{5}$$

$$Q = \frac{U_{PCC}^2}{R}\left(\frac{1}{\omega L - \omega C}\right) \tag{6}$$

So

$$U_{PCC}^2 = PR \tag{7}$$

$$\omega = \omega_0 \left(\sqrt{\frac{1}{4\lambda^2}\left(\frac{Q}{P}\right)^2 + 1} - \frac{1}{2\lambda}\cdot\frac{Q}{P} \right) \quad (8)$$

And

$$\frac{df}{dt} = -\left(\frac{P_L - P_G}{2H * S_{GN}} * f_r\right) \quad (9)$$

As a result of the continued interconnection of RESs, islanded mode operation of these RESs will be an unavoidable issue in the future [16]. LOM detection is crucial for the safe operation and stability of the power system grid with RES integration. Islanding detection methods can be broadly classified into the remote methods and local methods of islanding detection as highlighted in figure 3 below [17] [18].

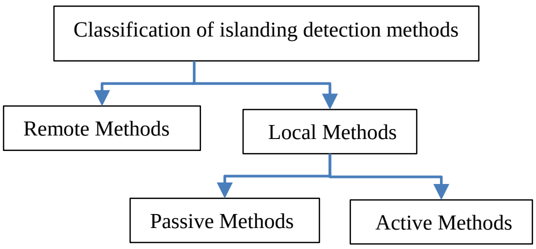

Figure 3: Islanding Detection Methods Techniques

2.1 Local Islanding Detection Methods

Local islanding detection methods can be grouped into two categories: that is, active and passive techniques of LOMs and islanding detection. These are elaborated in the subsequent subsections below.

2.1.1 Passive LOM and islanding detection methods

These methods use the local measurements at the DG side and monitor for sudden electrical parameters variations. The grid voltage, frequency, phase angle and total harmonic distortion are monitored to detect the LOM and islanding condition [19]. If these monitored parameters goes outside the set limits, then the connected relay opens and disconnects the DG from the system. Using changes in OUV or OUF [20] [21] [22], ROCOF or ROCOV [23] [24], fast changes in the voltage phase, voltage harmonic monitoring, etc., these methods discern LOM and the occurrence of islanding condition of the monitored MG.

These methods are generally simple and cheap to implement. Moreover, they don't have any effect on the power quality in islanding detection [25] [26]. They however show a large non-detection zone (NDZ) [27], i.e., when the generated power by the DG is equal to the power absorbed by the local loads and no power is therefore imported from the utility grid. In this case, the variation of the grid variables is negligible, and the anti-islanding algorithms cannot detect the islanding situation [28] [17] [29]. As a result of this, these methods are not suitable for LOM and islanding detection in MGs with multiple RESs [30] [31]. Figure 4 below shows the flow chart for the LOM and islanding detection using passive method.

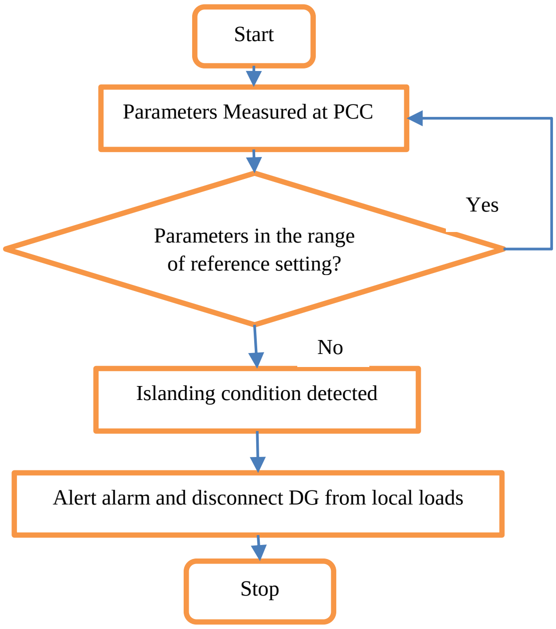

Figure 4: Flow chart for passive method

2.1.2 Active LOM and islanding detection Techniques

These techniques of loss of mains were devised to overcome the weaknesses of passive methods of islanding detection. They identify an LOM condition by applying small perturbations or use a positive feedback [32] and then observe the changes in system parameters when the DG is islanded [33] [34]. Moreover, these techniques are characterized by simplicity with a high efficiency, good accuracy and very reliable [35]. Examples of active methods include impedance measurement [36] [37], active frequency drift [38], frequency jump method, Sandia frequency shift [39], sliding mode frequency shift, phase distortion method [40], harmonic injection method [41], Sandia voltage shift, power variation monitoring, and reactive power export error detection.

Most of these active IDMs have not discussed the islanding detection in multiple generators. In reference [42], Reigosa and others discussed briefly a case of multiple DGs islanding detection using the injection of signals at high frequency levels. However, they proposed the injection of these signals from the master DG as other DGs act as slaves in the system. This lowers the islanding detection accuracy in the absence of the master DG. Despite their merits, these active methods introduce undesirable disturbance in the grid, which should be kept as small as possible especially in MGs with multiple RESs as this can cause interference between DGs operating in parallel [17]. These methods also have poor performance in the presence of multiple DGs in a MG [43]. A detailed survey on LOM and active islanding detection methods is discussed in references [44], [45] and [46]. Figure 5 below shows a flow chart for active loss of mains and islanding operation detection techniques.

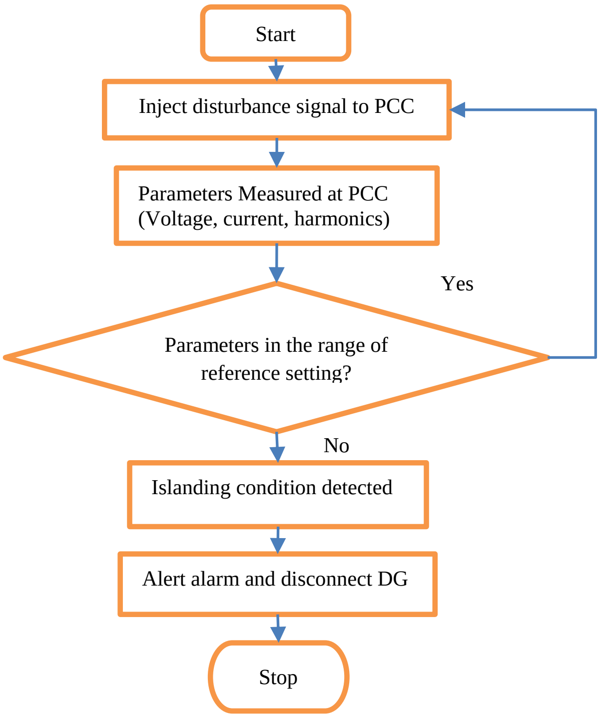

Figure 5: Flow chart of Active Method

2.2 Remote Islanding Detection Methods

These methods were developed to overcome the challenges and demerits of local LOMs and islanding detection methods. They are also known as communication based islanding detection methods. These methods can be broadly categorized into three groups: Supervisory Control and Data Acquisition based methods (SCADA) [47], Power Line Carrier Communication (PLCC) methods [48], and methods that monitor the device used to connect or disconnect from the grid [49] [50].

Basically, the SCADA technique monitors the grid system parameters like currents, voltages and frequencies of the circuit breakers and transfer them to the main control centres. On the other hand, PLCC method, has transmitters which are used to produce the status signals and transmit them on the power lines to the central point for making decision on islanding condition. These methods do not have NDZs and are grid friendly. They are applicable to the systems with multiple DG units. This include both inverter-based sources and synchronous generators. However, they are not very unpopular due to the need of an ample and reliable communication system between the DG and the utility grid. This is a costly undertaking especially for small MGs [43].

2.3 Hybrid islanding detection methods

These techniques were devised in order to overcome the drawbacks of both the active and passive techniques in LOMs and islanding detection and to optimize on their merits. To achieve this, the two methods are combined so as to improve the accuracy of the system [51] [52]. The two combined methods are not used concurrently. The active method is only employed after the island is first detected by the passive method. This acts to verify the fact that an island has occurred or not, hence increasing the accuracy. This does not have a great impact on the quality of power and significantly reduces the NDZ.

2.4 Modern islanding methods

These are the most used techniques currently due to their efficiency and high accuracy. They make use of signal processing methods in the extraction of the signal and its classification as islanded or not islanded. This greatly improves the accuracy in LOMs and islanding detection and the performance of the entire system. Examples of these techniques of islanding detection include and not limited to: mathematical morphology, HH transform, TT transform, Wavelet transform, S-transform [11], among others.

The current research trend has shifted to the combination of the passive techniques and artificial intelligence (AI) algorithms in islanding detection. These methods have proven to be having high efficiency, accuracy, reliability and can be applied for online monitoring of the power grids [35]. There are a number of examples of these modern hybrid techniques. For instance, Gaing combined DWT with PNN in power disturbance classification [53], Othman combined PNN with WT for fault identification and location [54], Yin also used a combination of Fast Fourier Transform and Artificial Neural Network for islanding detection [55] and also Elnozahy used a combination of WT and ANN in islanding detection [56] among other hybrid methods.

2.5 Analysis of Classical LOM Detection Methods

There are many and different LOMs detection methods developed that have been used for different types of DGs and their operating conditions. Some islanding detection methods are suitable for synchronous-based generators while others are suitable for inverter-based DGs [57]. Generally, there is no universal islanding technique that can work for all the different DG systems. Each technique has its merits and demerits and the choice of methods to implement requires a compromise between merits, demerits, cost and desired reliability among others. Table 1 below presents a comparative analysis of some of the conventional characteristics of the different classical islanding detection techniques.

Table 1: Comparative analysis of islanding detection methods

Technique	NDZ	Detection Time	Power Quality	Cost	Detection Reliability	Effect on multiple DGs
Passive methods	Large	Short	No effect	Low	Low	None
Active methods	Small	Long	Degradation	Medium	High	Synchronization issues
Hybrid methods	Small	Long	Degradation	High	High	Synchronization issues
Machine learning	Small	Variable	No effect	High	High	None
Remote methods	None	Very short	No effect	High	Very high	Increase in cost

3. TECHNICAL ASPECTS ANALYSIS OF LOMs AND ISLANDING DETECTION

Islanding condition can be broadly classified into unintentional and intentional islanding operations. By definition, intentional islanding can be defined as the process of knowingly and willingly splitting the grid into small and separate controllable sections so as to mitigate cascading effects and its eventual blackouts [58]. This is done in order to mitigate or minimize the effects of unintentional LOMs and islanding. This immensely improves the system efficiency, voltage profile and also reduces both transmission and distribution congestion. The system frequency and voltage are expected to come back to their normal limits upon accurate islanding detection so as to avoid further or impending blackouts in the system [59]. In case of intentional islanding scenario, each islanded MG may have different unit price which should also be controlled to avoid exploitation of customers. The producers should give the customers the choice of either buying electricity or not under this condition [13].

On the other hand, an unintentional islanding occurs when the main grid is lost without the knowledge of both consumers and utility supplier. The DGs in the isolated MG continues supplying the local loads. The LOMs in unintentional islanding can take place under any of the following conditions [11]:

- The presence of a fault upstream of a MG that is detected by the protection mechanism of the main utility grid but goes undetected by the DG's protection system
- Failure of the utility equipment that eventually leads to unintentional LOMs and islanding and
- Through a natural occurrence and catastrophes, for instance an earthquake among others.

The IEEE 1547-2003 standard requires an immediate disconnection of any unintentional island within two seconds of its occurrence. This is illustrated in the table 2 below [60] and other international standards of operation limits for ensuring a safe, reliable, and standard quality supply to all end user loads existing within the island as shown in table 3 [61].

Table 2: IEEE Abnormal Voltage Range and their recommended Clearing Times.

Percentage voltage range	Clearing time in seconds
V<50%	0.16
50%≤V<88%	2
88%≤V<110%	Normal operation
110≤V<120%	1
V≥120%	0.16

Table 3: Standard Power Systems Voltage and Frequency Limitations

Reference standard	Frequency Range	Voltage Range
IEEE P1547	0.99 – 1.01	0.9 - 1.1
VDE 0126, OVE E2750	0.94 – 1.02	0.8 – 1.15
CEI 0-21, CEI 0-16	0.994 – 1.006	0.8 – 1.2

For effective integration of RESs into the existing power grid, there is need for fast and reliable unintentional islanding detection methods [37]. Unintentional LOM is undesirable occurrence due to a number of reasons. This include and not limited to the following.

- DGs are generally weak power suppliers and hence they are not capable of handling system transients efficiently as required by the grid during a fault
- In some instances, there may be out of phase reclosing during the fault time and this may seriously damage both the customers and the utility equipment.
- Voltage and frequency instability and deterioration in case demand do not match with the supply within the island
- Posing of a health and safety hazards to utility workers who may not be aware that isolated island is still powered by the local DGs in the MG
- Loss of grounding within the islanded MG as the power systems usually have the earthling point at the utility side.

4. CRITERIA FOR PERFORMANCE ANALYSIS OF AN ISLANDING DETECTION TECHNIQUE

There exists a number of methods of gauging the performance of an Islanding Detection Method (IDM) and each is only suitable for a given technique. The effectiveness, accuracy and fastness are some of the parameters that are used to determine the particular islanding detection method’s performance [62]. For instance, the Non Detection Zones (NDZs), reliability, power quality effect, the cost of implementation and run on time are some of the criteria used as discussed in the sections that follow.

4.1 Non Detection Zones

These are the conditions in a MG when the differences between supply and demand is very small to the extent that an IDM fails to detect the LOMs and islanding operation. This is one of the main methods of determining the performance of IDM. The small the NDZ in a given method, the higher the performance. The power mismatch space and the load parameter space are mainly used in the detection of an island [63]. The NDZ methods based on monitoring voltage, frequency or phase deviation is often described in power mismatch space (PMS) while the NDZ methods that are based on disturbance injection is usually described in load parameter space [48].

For an IDM that is based in frequency changes, the Load Parameter Space is the most appropriate. Equation (10) below is often applied to match the NDZ of the techniques used for islanding detection in the phase criteria. However, the NDZ of an islanding detection technique can be foretold using this method but cannot give the actual islanding detection time. Therefore, different curves needs to be plot for different loads analyzed.

$$C_{norm} = {}^{C}/_{C_{res}} * w_0^2 * L \tag{10}$$

When the DGs are operating is grid-connected mode, the main objective is to supply constant power to the grid as per the agreement. However, this is not the case when in islanded operation mode. Here the DGs should be configured to control the frequency and voltages for equipment safety purposes. Additionally, the DGs should also have as small NDZs as possible in order to accurately detect the LOMs cases. Equations (11) and (12) below illustrate the power mismatch conditions that can lead to failure to detect LOMs and islanding condition.

$$\left({}^{V}/_{V_{max}}\right)^2 - 1 \le {}^{\Delta P}/_{P_{DG}} \le \left({}^{V}/_{V_{min}}\right)^2 - 1 \tag{11}$$

$$Q_f\left(1 - \left({}^{f}/_{f_{min}}\right)^2\right) \le {}^{\Delta Q}/_{P_{DG}} \le Q_f\left(1 - \left({}^{f}/_{f_{max}}\right)^2\right) \tag{12}$$

Using the above two equations, the NDZ scenario can be pictorially represented by the diagram in figure 6 below. Using this information the NDZs for different standards of islanding detection can be elaborated in table 4 below. However, when the reactive and active power differences are very small and lie within the set limits, their corresponding voltages and frequencies will also lie within the set standards and hence islanding condition and LOMs will not be detected.

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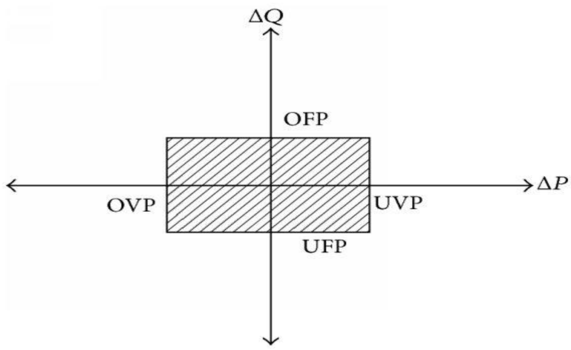

Figure 6: NDZ Schematic diagram

Table 4: Power Mismatch Space for different islanding standards

Islanding standard	Max Time (sec)	Max Voltage (%)	Min Voltage (%)	Q_f	Percentage PMS			
					$\left(\Delta P/P_{DG}\right)_{min}$	$\left(\Delta P/P_{DG}\right)_{max}$	$\left(\Delta Q/P_{DG}\right)_{min}$	$\left(\Delta Q/P_{DG}\right)_{max}$
IEEE1547-2003	2	110	88	1	-17	29	28	31.7
UL 1741	2	110	88	2.5	-17	29	72	79.2
Korean STD	0.5	110	88	1	-17	29	28	31.7
IEEE929-2000	2	110	88	2.5	-17	29	72	79.2

4.2 Run on time

The Run on Time (ROT) is the time taken from the instance the PCC Circuit Breaker (CB) is opened till the DG is disconnected. To minimize the chances of damaging utility and customer equipment, the run time should be as minimal as possible. The run time is as illustrated in equation (13) below.

$$T_{rt} = T_{mcb} + T_{com} \quad (13)$$

4.3 Nuisance tripping

When the NDZ is set to a very small value, it will at times lead to unnecessary and nuisance tripping. The margin should be considerate so as to avoid this effect that can be as a result of either heavy load switching and related disturbances which are normal in networks [64]. This phenomenon is usually expressed as a percentage of the overall cases of LOMs and islanding detection. An illustration of this is as shown in equation (14) below. To avoid unnecessary disconnection of the DGs from the system, this percentage should be as small as possible.

$$P_{nui} = \left[\frac{I_{nui}}{(I_{nui} + I_{ist})}\right] * 100 \quad (14)$$

Where; I_{nui} is the nuisance instants, I_{ist} is the islanding instances and P_{nui} is the percentage nuisance.

4.4 Effect on MG

The effect on the power quality caused by any IDM is another indication of its performance. The signal injected to the grid by an IDM should be as minimal as possible if not none. These signals injected into the system normally have no effect when the DGs are operating in grid connected condition but bring significant effect when there is loss of mains and the system is islanded. Hence any active IDM that inject minimal signal to the system is preferred in this case.

5. ISLANDING DETECTION CONSIDERING MULTIPLE DGs IN MGs

The islanding detection methods discussed above have generally been motivated by the early efforts to integrate single DGs, either in the form of PV or wind energy sources, into electrical grids separately and directly implemented within the generation source in a MG. However, this is not the case currently as grids keep on evolving into smart grids. More often than not, more than two DG sources of various technologies are incorporated in the same MG in parallel operation. This makes it a challenge to implement IDMs in each DG as they may interfere with each other.

This, therefore calls for islanding detection methods that can comfortably be applied in these MG systems with multiple energy sources. Moreover, these IDMs should have the ability of operating in multiple DGs in the same MG. From the analysis, the performance of an islanding detection technique directly relates with cost of the islanding detection method used. This is a challenge for small MGs with little investment. As a result, a compromise between cost and accuracy need to be arrived at in deciding which IDM technologies to deploy.

It is also necessary to carefully extrapolate the islanding detection concepts to the next steps in technology evolution. The first obvious step in the technology evolution being the extension of single DG integration concepts to the multiple-DG cases in the same MG. References [65], [66] and [67] have tried to analyse this concept where each DG has an islanding detection responsibility within itself. Most of these analysis, however, considers multi-DGs of the same source, for instance solar PV sources only. Table 5 below compares the various hybrid islanding detection methods with various RESs in a MG with their strengths and weaknesses.

Table 5: Comparison of hybrid Islanding Detection methods with various RESs

Islanding Detection Method	Generation system used	Main method	Reference material	Strengths	Weakness
Passive method	Synchronous	Rate of change of frequency	[68]	Low detection time	High NDZ
	Inverter based	Harmonic parameters	[69]		
Hybrid method	Synchronous	PF and Voltage unbalance	[70]	Small NDZ and detection time	Slightly degrades power quality
	Wind	Real Power Shift	[71]		
Remote method	Photovoltaic	Transfer trip	[72]	No NDZ	High cost
	Photovoltaic	Power lone carrier communication	[73]		

After successfully detecting an islanding condition in a MG with multiple DG units within an island, the DGs will be required to serve the existing load by sharing it in an active way [74] [75]. This can be achieved by configuring the system to automatically change from the grid connected mode to voltage control mode.

5.1 Comparison of Signal Processing and Islanding Classification Methods Considering Multiple RES

It is very important to set an appropriate threshold so to avoid nuisance tripping and failure in islanding detection. However, choosing a right tool to use to get the required accuracy is not an easy task. Currently, there are islanding signal classifiers which have proven that they can achieve the required accuracy and thus improving islanding detection reliability. These include and not limited to decision tree (DT), Artificial Neural Network, static vector machine, artificial neuro-fuzzy inference system, fuzzy logic, among others [11].

In reference [31], Mohammadzadeh presented a paper that uses empirical mode decomposition (EMD) technique, which is a key part of the Hilbert–Huang Transform (HHT), to detect islanding condition. The strength of this method is that it works very well in multi-DG systems and it is very simple to implement. Tables 6 and 7 below summarizes the comparison of the signal processing and classification methods considering multiple DGs in a MG. In his paper [76], Ahmad presented a method that uses voltage index to detect islanding for multiple DGs in a MG. However, they used wind farms in this analysis. Laghari and others proposed a strategy that can detect islanding for multiple mini-hydro type DG units by observing only rate of change of reactive power [16]. However, they noted that for close power mismatches, this method could only detect the LOM and islanding by initiating the Load Connecting Strategy (LCS) [16].

Table 6: Comparison of signal processing methods with multiple DG sources

Signal processing method	Generation Method	Signal Analysed	Article	Strength of the method	Method weakness
Hilbert–Huang Transform	Inverter based	The voltage at PCC	[77]	Provides physical representation of data	Less suitable for close frequency component signals
Stockwell Transform	Wind and solar Photovoltaic	Negative sequence of voltage at the PCC	[78]	Simple multiresolution ability	Fails in localization of momentary phenomenon
	Solar PV, wind and Fuel cell	Negative sequence of voltage at the PCC	[79]		
Hyperbolic Stockwell Transform	Solar PV, wind and Fuel cell	The voltage at PCC	[80]	Better time and frequency resolutions for high and low frequency	Window fails to include all signals
	Wind and solar Photovoltaic	Negative sequence of voltage at the PCC	[81]		
Time-Time Transform	Solar PV, wind and Fuel cell	The voltage at PCC	[4]	Better understanding of time-local properties of the time series	Not suitable in low frequency localization applications
	Solar PV and wind	Negative sequence of voltage at the PCC	[82]		
Mathematical Morphology	Wind and Solar Photovoltaic	Negative sequence of voltage at the PCC	[78]	More computationally simple	Reconstruction of the original signal is not possible

Table 7: Comparison of classifier methods with multiple DG sources

Classifier	Generation Method	Signal processing Technique	Article	Strength of the classifier	Shortcoming of the classifier
Decision Tree	Synchronous	Not indicated	[83]	Fast training	Unfit for cases having lot of un-correlated variables
	Not specified	Discrete Wavelet Transform	[84]		
	Synchronous	Not indicated	[85]		
Artificial neural network	Synchronous	Not indicated	[86]	Easy implementation	Huge cases required for proper training
	Photovoltaic	Discrete Wavelet Transform	[87]		
Probabilistic Neural Network	Not specified	Discrete Wavelet Transform	[88]		
Static Vector Machine	Photovoltaic, fuel cell and wind	Stockwell Transform	[89]	Minimized training error	Choice of proper hyper parameters is cumbersome
	Photovoltaic and wind	Stockwell transform, Hyperbolic Stockwell transform, Time-time transform, Mathematical morphology	[81]		
Adaptive Neuro-Fuzzy Inference System	Wind, Diesel and Ni-Cd battery	Discrete Wavelet Transform	[90]	No requirement of mathematical models	Both the knowledge of ANN and Fuzzy is required
	Doubly Fed Induction Generator	Not indicated on the paper	[91]		

5.1.1 Voltage and current harmonics detection

This method uses total harmonic distortion (THD) measured at PCC to detect islanding condition [92]. The merit of this method is that it is consistent in frequency when multiple DGs are connected to the same PCC in parallel in the MG, it is also easy in implementation and fast islanding detection time [62]. However, this method has a challenge in selecting thresholds as grid disturbances can easily cause error in detection and it also fails if the NDZ is large for those loads with large Q factor.

5.1.2 Islanding detection in multi-inverter systems

A number of researches based on passive islanding detection methods have been done but few have looked into the islanding detection in multiple RESs of different technologies in a system [32]. For instance, Reigosa and others [93], proposed a method for islanding detection for multi-inverter system using a high frequency injection. The system was divided into master and slave inverter where only the master inverter injects the perturbation as others only participate in islanding detection. In [32], Emadi proposed an active islanding detection method for multi-inverter systems which works based on perturbation of direct and quadrature axis reference currents of inverters. To avoid interaction of the inverters, perturbations injected were synchronized according to voltage phase at PCC.

In his paper, Luiz [94] presented cases for interference and also analysis of the performance of active frequency drifting in multi-inverter DG islanding detection. Generally, it is a common assumption that systems which have multiple inverters equipped with active islanding detection methods, can fail to detect the LOMs and islanding condition by the non-islanded inverters due to interference [95] [96]. With the continued increase in deployment of the PV systems in the grid, multiple inverters in the same MG will be a common practice and hence it will be important to carry out more research on the effect of these DG inverters on islanding detection [94].

5.2 Future Trends in islanding detection

As grids are continuously being transformed to smart grid and advancing technology, the islanding detection techniques should be also be changed in tandem with these changes. There should also be continuous research on these techniques so as to be in par with these changes. The aspects that needs more light to be shed on then include the following;

- Employing some of the new and advanced signal processing loss of mains and islanding detection techniques in MGs with multiple RESs.
- Investing on modern ways that can be used to avoid occurrence of total blackouts irrespective of the presence of critical loads within the MG. This will be in line with the continuous evolution of smart grids
- Smart distributed grid has been proved that it can improve the efficiency and reliability of the power system. Network-based hybrid distributed control of MGs is essential to optimize the performance of MGs under high-penetration level of DG resources.
- Although hybrid power system has many advantages such as reduced power loss and high reliability, it has to face challenges of some new control problems. The control problems include how to detect the loss of mains fast and accurately.

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