ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Comparison and Review of Islanding Detection Techniques for Power Distribution Studies

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ABSTRACT: Detecting and fixing the potential occurrence of islands in power distribution networks with distributed generation systems is becoming a difficult task. Islanding is the condition in which DG operates without interruption and feeds distribution lines when the connection of the utility grid has been cut off. Generally islanding detection techniques are classified as remote methods, which detect islands on the utility sides, and local methods, which detect islands on the DG side. This paper presents a comparison and review of various islanding detection techniques. A summary table that compares and contrasts the existing methods with respect to detection time, Non Detection Zone, and effect on power quality has been shown.

KEYWORDS: Grid-interconnection; Distributed Generation; Islanding; Overvoltage; Under-voltage; Over-frequency; Non-detection Zone; Passive Islanding Detection; Active Islanding Detection; Security.

I.INTRODUCTION

In conventional power distribution systems, electrical energy at the distribution level was always supplied to the customer from upstream power resources which were connected to the bulk transmission system. In order to exploit the benefits of local power generation, distributed generation concept was introduced. The power resources include photovoltaics (PV), wind farms, tidal, micro-hydro turbines, biomass and geothermal energies. The benefits of using DG are reduced environmental effect, increased efficiency, avoidance of capacity enhancement for transmission and distribution (T&D), and reduced T&D line losses [1–5]. However, various problems need to be addressed before the DG units are used. These problems include frequency stabilization, voltage stabilization, intermittency of the renewable resources, and power quality issues. The formation of the micro-grid (MG), which is caused by the disconnection from the main grid without stopping the energy generation from the DG sources, can also be considered as a drawback of DG [6]. The disconnection of the main source is called islanding, which can be either intentional or unintentional. Intentional islanding is the formation of power "island" during system disturbances, such as faults. Undetected island leading to formation of a micro-grid is generally called "unintentional islanding" [7,8].

Unintentional islanding of DGs can give rise to difficulties in terms of power quality, safety, voltage and frequency stability interference [3–5, 9, 10]. The IEEE 1547–2003 standard has specified a maximum delay of 2 s for the detecting unintentional islanding condition; the IEEE 929–1988 standard requires the disconnection of the DG if islanded [3,4]. Therefore, finding effective solutions to overcome this problem is essential. The literature shows several technical publications related to islanding detection.

Non-Detection Zone: Islanding detection is defined by an index called Non Detection Zone (NDZ). In Fig.3, range of NDZ for the operation of the relays is indicated. NDZ is defined as the limits of real and reactive power mismatches, that do not lead to increase in the voltage or frequency above the preset value, which may otherwise cause islands. NDZ is measured in terms of voltage, frequency or phase deviation, which is often defined in power mismatch space.

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During islanding, variation of voltage and frequency, at the point of common coupling (PCC), is related to thedifference between power output of DG and load consumption [6]. Power mismatches, both active and reactive are

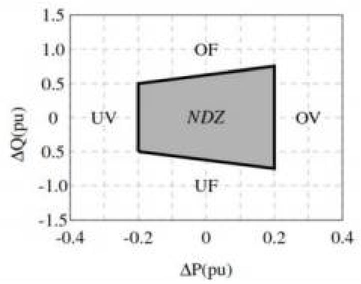

Fig.1. Non-Detection Zone

nearly equal to zero when DG power output and load are almost balanced.

II.ISLANDING DETECTION METHODS

For maintaining effectiveness, an islanding detection technique should have the ability of detecting island without delay, ensuring safety, reliability and integrity of the entire system. Also, it should uphold the local voltage and frequency within its regulation limit throughout the process of islanding. Islanding detection methods are broadly classified into three groups: active, passive and communication based.

A. Remote Techniques: In remote techniques, communication between the grid and the DG is taken into consideration. It is reliable than localtechniques but quite expensive.

1. Power Line Carrier Communication: In PLCC, a signal is sent from the grid to the DG continuously. The power lineis used as the communicating medium for the signal. The signal continuity is monitored for detecting islands. Thistechnique requires a signal generator in line with the grid that continuously relays to a signal detector at the DG [11].

2. Supervisory Control and Data Acquisition (SCADA): Supervisory control and data acquisition (SCADA) is used to detect islands. A master unit and a number of distributed remote terminal units (RTUs) connected to the master via varieties of communication channels, constitutes SCADA system. A SCADA system includes a master and a number of remote terminal units. The remote terminal units are connected to the master through varieties of communication channels. The speed of data acquisition and control relies on the communication channel [3-5, 12].

3. Intertripping: Whenever contacts at points of disconnection open, a signal is transmitted to the generation sites by this method. These generation sites support the islanded zones. The communication between the sensors and generating units are also used by this method to find islands. Intertripping is very reliable and accurate but is expensive [13].

B. Local Techniques: Local techniques rely on the DG side data and can be grouped into the following,

1. Active Techniques: In islanded mode, active methods make the DG unstable. The active methods have a small NDZ which makes it better than passive methods. In active island detection, a perturbation is introduced in terms of frequency or the voltage at the point of common coupling, till the protection relays such as under frequency relay/over frequency relay (UFR/OFR) or under voltage relay/over voltage relay (UVR/OVR), respectively, is tripped.

1.2. Impedance detection: In the grid impedance detection technique, a disturbance in the inverter output current is added periodically by the inverter-based distributed generation (IBDG). If the PCC voltage remains unchanged throughout the disturbance, the IBDG presume that the grid (usually has a low source impedance) is still maintaining

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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the PCC voltage and the IBDG continues its operation without interruption. But when the voltage at the terminals of the PCC varies with respect to the current disturbance, the impedance at the IBDG terminals is higher, the grid is disconnected and the inverter is islanded [3,4]. The impedance detection method based on islanding detection does have a NDZ in the single inverter systems.

1.2. Change of output power: In this technique, IBDG's power output is varied to interrupt the balance between the source and the load. For this particular technique to work, time synchronization among all the IBDGs is an important criterion. Otherwise it may lead to a failure due to the averaging effect. [5].

1.3. Automatic phase shift(APS): In this method, change in the starting angle of the output current of IBDG with respect to the frequency of the terminal voltage of IBDG is taken into account. Whenever the frequency of the IBDG terminal voltage stabilizes, another phase shift is added. The frequency of the terminal voltage keeps deviating until UF/OF relay is tripped [14].

1.4. Active frequency drift: In active frequency drift (AFD) technique, the current is slightly distorted presenting a zero current segment. The phase difference between the IBDG terminal voltage and the current is load dependent. When the grid gets disconnected, the phase difference between the IBDG voltage and the current will vary. To eliminate the phase difference, the frequency drifts up or down till the OF/UF relay is tripped [15, 16].

1.5. Slip mode frequency shift: In Slip mode frequency shift (SMFS), the starting angle of the IBDG output current changes with frequency of the terminal voltage at each zero crossing [17]. To indicate islanding, this technique applies a positive feedback to shift the phase (therefore frequency) of the voltage at the PCC terminals.

1.6. Reactive power export error: It is an improved phase shift method. In this method, reactive power of the power system is varied periodically. This results in a phase shift between the output voltage and current, which increases or decreases the load voltage frequency during islanding and therefore the OF/UF relay is tripped [5].

1.7. Sandia frequency shift: In this technique, a zero-current segment is introduced per half of the line cycle. A positive feedback is used to initiate frequency based islanding detection [18, 19].

1.8. Sandia voltage shift: SVS technique is almost same as to that of SFS, except that it introduces a change in the amplitude of the PCC voltage rather than frequency [18].

1.9. Harmonic current injection: In Harmonic current injection technique, a disturbance is injected in the grid through the daxis or through the q-axis current components of IBDG [20].

2. Passive Techniques: In Passive techniques system parameters are measured and compared with a threshold. A major problem while designing a passive islanding detection technique is during the selection of a suitable measure and adjusting its threshold value. Passive techniques have a large NDZ in comparison to active techniques. Several passive islanding detection techniques are described below.

2.1. Under voltage/over voltage: Under voltage/over voltage (UOV) islanding detection is one of the easiest passive techniques used. This technique is designed according to the change in voltage during islanding phenomenon. One major disadvantage is, if the load power and the generated power by the DG during islanding are matched, the voltage and frequency change will be very negligible [9]. In [21], for voltage sag detection, an algorithm based on rectified voltage processing is mentioned. This algorithm considers sag in voltage sag that is be used to trigger the detection technique as it exceeds a certain threshold [21].

2.2. Under frequency/over frequency: In UF/OF technique, the frequency change introduced during an islanding phenomenon is compared to a preset threshold to detect islands [22].

2.3. Rate of change of active power: During islanding, the voltage at the PCC terminals varies when the difference in active power variation flows into the load. This variation of voltage can be a sign of islanding [23].

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

2.4. Rate of change of frequency: In synchronous generators, Rate of change of frequency (ROCOF) is the most preferred technique for island detection. A variation in power is introduced when the grid is disconnected, during island event. This power difference results in change of frequency which is used to detect the islanding. If the disturbance in power is small, the frequency varies slowly [22,24,25].

2.5. Rate of change of frequency over power: A threshold counter is defined to check islanding. When the detection index is greater than the threshold, the counter is incremented by one. When the counter is greater than a predefined threshold, islanding is detected [26].

2.6. Voltage and power factor change: Island is detected when the ROCOV is positive and the variation in power factor ranges between 0.10 to -0.50 [27].

2.7. Comparison of rate of change of frequency: This technique works on the abrupt variation in frequency owing to the disconnection of the grid, also called LOM (loss of mains) as in ROCOF. In comparison to ROCOF, COROCOF distinguishes between variation in frequency owing to loss of mains and variations owing to system disturbances [28].

2.8. Phase jump detection: During loss of mains, the phase angle between the inverter output current and the PCC voltage is load dependent. Island is detected if the phase angle variation exceeds a predefined threshold. The PJD technique searches for a rapid change in phase angle to detect islanding as shown in Fig. 2. This method has easy implementation because only modifying the phase locked loop (PLL) required by the inverters for utility synchronization is needed. The capability to deactivate the inverter is only required when the phase errors exceed some threshold. This method has no effect on the powerquality of the inverter and is used in multiple inverter systems [17].

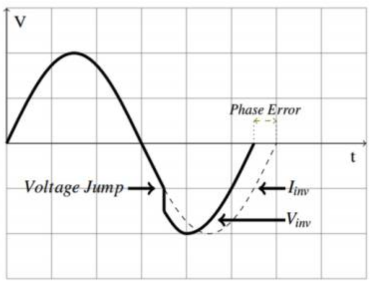

Fig. 2. Representation of voltage jump leading to phase error

2.9. Voltage unbalance and total harmonic distortion: Monitoring of VU at the PCC and THD of the DG output current and comparing themwith their respective thresholds is used for island detection. The major disadvantage of this technique includes, change in VU/THD caused due to load switching, even in grid-connected mode [29,30].

2.10. Vector surge relay: Vector surge relay (VSR) is used for islanding detection. During loss of mains, disturbance in power balance between the DG and load results in the acceleration or deceleration of DG; thus causing a change in terminal voltage vector. On every zero crossing (rising) of the terminal voltage, VSR updates its measured parameter. When the terminal voltage reaches minimum, this relay triggers due to its blocking function. The trip signal from the VSR gets blocked, when the terminal voltage goes below the threshold value for the voltage, thus avoiding tripping for generator start up or short circuits [22, 30].

2.11. Wavelet: The wavelet theory is the mathematical model for non-stationary signals with a set of components in the form of small waves called wavelets. The original wavelet is generated from one original wavelet called the mother wavelet, which is then further extended to allow the wavelet to analyse the non-stationary signals in the frequency band.WT can be either continuous (CWT) or discrete (DWT). The advantage of Wavelet is that the wavelet does not require assuming the stationary or periodicity of signal. Wavelet has long windows at low frequencies and short windows in high frequencies, which makes it capable of comprehending time and frequency information

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ISSN (Online): 2278 – 8875

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Vol. 5, Issue 7, July 2016

simultaneously. Thus, in time-varying signals WT can control the discontinuities and transients to boost islanding detection studies [31-35].

2.12. Neural network: The artificial neural network (ANN) is a computational structure model of a biological process that attempts to implement the mathematical model instead of using a biological brain neural network in which the brain contains all the useful information and the data memory. This model has numerous interesting and attractive features that can be used to identify any changes in the data. Therefore, the model is widely used in numerous areas, including in islanding detection [36]. The ANN is usually used with a signal processing technique such as WT.ANNs were also combined with the wavelet to detect islanding. The DWT was used to extract the feature from

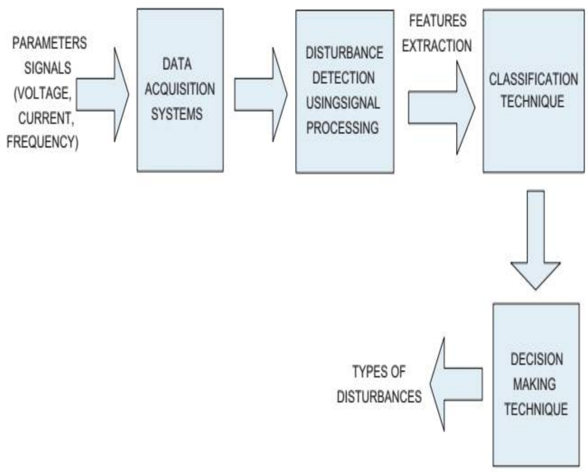

Fig.3. Block diagram of intelligent islanding detection

current signals. The signal was then extracted using a correlation coefficient and was validated using ANN. Only one signal was analysed and only one of the ANN input is used to detect the islanding condition. This technique showed high classification efficiency, which makes the algorithm suitable for a practical system.

2.13. Fuzzy Logic: The fuzzy logic (FL) technique can also be applied as a classification technique in islanding detection.In [37], FL based on three measurement parameters, which are voltage, ROCOF, and active power derivative (ROCOP), was proposed. The FL was applied only when the situation was uncertain or unclear in detecting the islanding.

2.14. Kalman filter: A Kalman filter for island detection is described. This technique detects islanding whenever there is a mismatch of energy between the estimated 3rd and 5th harmonics and the real ones [38].

The summary of the various Islanding Detection methods and their performances with respect to detection time, Index of Non Detection Zone, and effect on power quality has been shown inTable.1.

	Classification	Concept	NDZ	Detection Time	Disadvantage	Effect on power quality
Remote IDTs	Power Line Career Communication	Communication through power line	No	Very Small	Complex	Yes
	Supervisory Control and Data Acquisition	Data acquisition			Costly	

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	Transfer Trip		Transfer Trip relaying			Complex	
Local IDTs	Active techniques	Impedance detection	Detecting the variation of grid impedance	Small	Small	False tripping	Yes
		Change of output power periodically	Changing the grid output power periodically		Small	Not practical	
		Automatic Phase Shift	A phase shift is introduced in the current		Small	Current distortion	
		Automatic Frequency Shift	A phase difference between voltage and current		Small	Current distortion	
		Slip Mode Frequency Shift	A variable phase difference between the voltage and current		Small	Current distortion	
		Reactive power export error	Changing the reactive power periodically		Small	Reactive power variation	
		Sandia Frequency Shift	Zero-current segment per half cycle is introduced		Small	Current distortion	
		Sandia Voltage Shift	Same as SFS except for voltage		Small	Voltage distortion	
		Harmonic current injection	Injecting current harmonics		Small	Current distortion	
	Passive techniques	Under/Over Voltage	Voltage variation	large	Average	NDZ	No
		Under/Over Frequency	Frequency variation		Average	NDZ	
		Rate of change of active of power	Active power mismatch		Average	Large NDZ	
		ROCOF	Frequency variation		Average	NDZ	
		Rate of change of frequency overpower	Both frequency and active power variation		Average		
		ROCOV and power factor change	Voltage and power factor variation		Average	Large NDZ	
		Comparison of ROCOF	DG ROCOF is compared with that of grid		Average	Large NDZ	

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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		Phase jump detection	Voltage phase difference		Average	Large NDZ	
		Voltage Unbalance/THD	Observing voltage unbalance and THD		Average	Spikes	
		Vector Surge Relay	Change in voltage vector		Average	Large NDZ	
		Wavelet	Spectrum variation		Average	Large NDZ	
		Neural network	Neural network		Average	Complex	
		Kalman filter	Harmonics Energy mismatch		Average	Complex	

VI.CONCLUSION

In this paper, an extensive analysis of the various systems of islanding detection techniques in a power distribution system has been presented. This paper enunciates and compares different islanding detection techniques The necessary features of islanding detection techniques and the potential of local and remote techniques used in the system have been investigated. An overview of the possible techniques used to determine the islanding condition is given and the improvement made on these techniques are highlighted for the convenience of readers and to create a broad spectrum.

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ISSN (Print) : 2320 – 3765
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