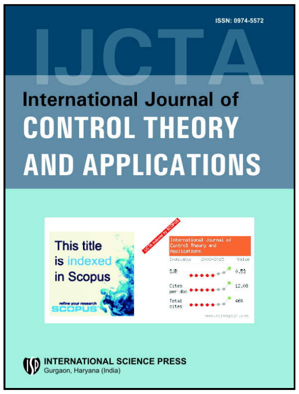

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 6 • 2017

Advanced Signal Processing and Soft Computing Techniques Based Islanding Detection: A Review

Basanta K. Panigrahi[1], Prakash K. Ray[*2], Pravat K. Rout[1], Asit Mohanty[3], Dillip K. Mishra[3] and Sibapriya Mohapatra[1]

[1]*Dept. of Electrical Engineering, SOA University, Bhubaneswar, India, Email: basanta1983@gmail.com; pravatrout@soauniversity.ac.in*
[*2]*Dept. of Electrical Engineering, IIIT, Bhubaneswar, India, *Corresponding Author, Email: pkrayiiit@gmail.com*
[3] Dept. of Electrical Engineering, CET, Bhubaneswar, India, *Email: asithimansu@gmail.com*

Abstract: This paper represents an overview of different advanced signal processing and soft computing techniques for detection of islanding disturbances in distributed generation (DG) based interconnected power system. Various passive islanding techniques such as Under/Over Voltage and Under/Over frequency, Voltage Phase Jump Detection, Harmonic measurement, Voltage unbalance etc. are discussed extensively for identification of islanding events. Further, advanced signal processing and soft computing techniques are being discussed for detection objective and are being compared w3ith the conventional passive techniques. It is highlighted that the signal processing and soft computing techniques provide faster detection with minimum non detection zone (NDZ). These techniques are observed to be more robust and flexible in dealing with complex nonlinear systems. Finally, a comparison between the different islanding detection methods are presented to know the relative merits and demerits.

Keywords: *Artificial Neural Network (ANN), Distributed Generation (DG), Decision Tree (DT), Fuzzy Logic Controller (FLC), Islanding, Wavelet Transform.*

1. INTRODUCTION

Conventional power system are known to be supplying power into different loads through transmission and distribution networks. This power system is highly interconnected and complex in characteristics. Because of increasing demand in electricity, environmental pollution, depletion of fossil fuels etc, the power engineers think of power generation from alternative energy resources like wind, solar, biomass etc. which are small-scale power generation technology known as distributed generation (DG). These resources are usually less than a few megawatts, and can be installed near to the load centers. Renewable distributed power generation system (RDGS) can provide many advantages compared to conventional power systems like low transmission and distribution losses, low carbon emissions, improved quality and reliability, better flexibility etc. [1, 2, 3]. In compared to the traditional grid system, DG resources are provided near the local load [1] to improve uninterruptible power supply. But the DG resources produce power quality and islanding disturbances because of their uncertain

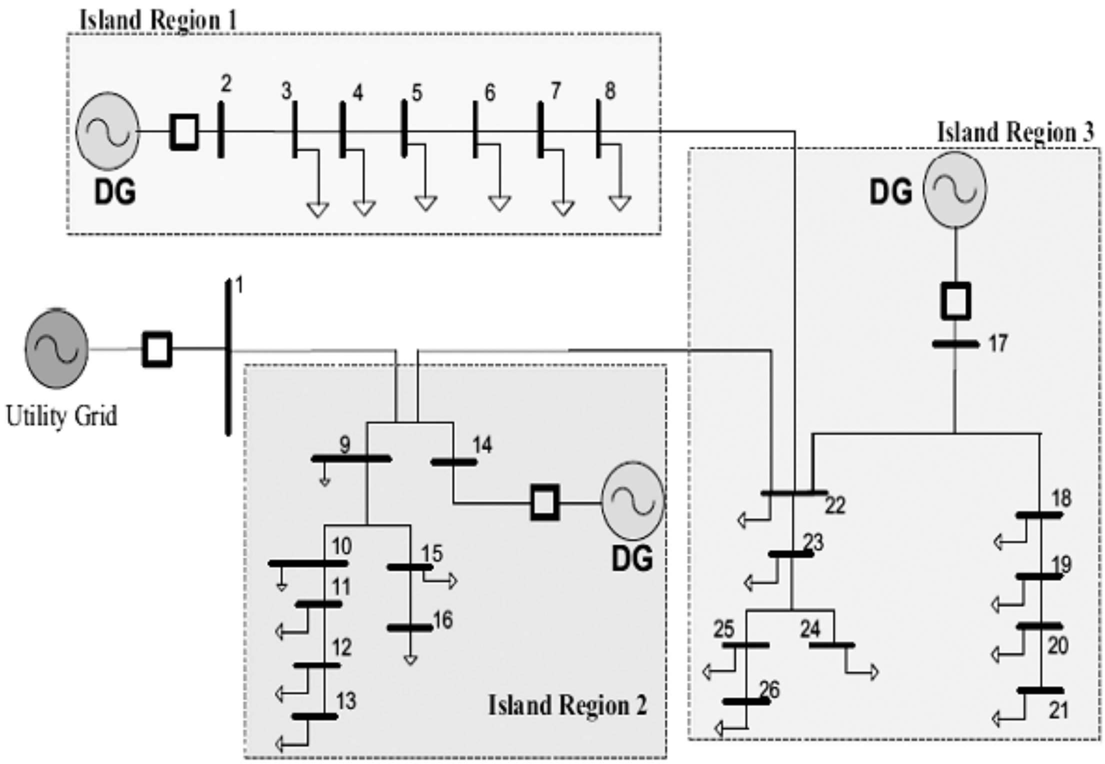

Figure 1: Islanding in multiple DG system.

characteristics. Islanding refers to a condition where the DG continues to deliver the local load even if it is isolated from the grid because of any abnormal condition as shown in Figure 1. Islands may be intentional or unintentional. The "intentional island" is aimed for maintenance purpose where region 1,2,3 can be isolated from the utility grid as displayed in Figure 1. by tripping some of the relays and circuit breakers. On the other hand unintentional islanding is caused because of some abnormal conditions in the grid side. In both the cases the local bus is subjected to variation in voltage, frequency, phase angle etc. leading to an unwanted operating situation in the DG based power system. This may badly influence the normal operation of the connected loads and the DG itself. This is potentially unsafe to utility personnel, because they may not know that still a part of the network is being fed from the isolated DG [4-8]. So, for all these reasons islanding must be detected as fast as possible and DG should be automatically disconnected from the load. IEEE 929-1988 standard [9] requires disconnection of DG once it is an island and IEEE 1547-2003 standard [3] provides a condition that islanding detection technology must be able to perform under all normal operating conditions, taking into account the unintentional various issues in islands [2-3]. Many techniques have been proposed to detect islanding in the literature. These techniques have been classified as a remote (central) and local method as shown in Figure 2. Remote islanding detection techniques can be classified into state monitoring, switch monitoring and interrupting. It is based on communication through utility and DG. Whereas detection techniques of local islanding can be classified as passive, active and hybrid techniques which is based on monitoring the system parameters at different points in the network.

2. PASSIVE TECHNIQUES

Islanding detection via local measurements with no interface is treated as passive techniques for islanding detection. In this case information collected from the DG side at the point of common coupling (PCC) and at utility grid is used in this passive islanding detection technique. Passive method relies on detection of any

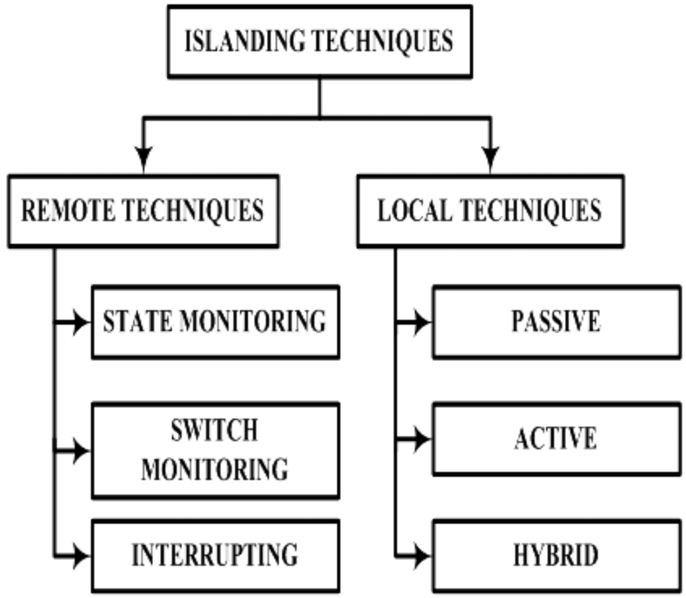

Figure 2: Classification of islanding detection methods.

abnormal behavior occurring in the power system because of some faults. Islanding is commonly detected based on the variation of frequency and voltage. Passive methods are fast, but they may lead to larger non detection zone (NDZ) [1-5], [10-14]. Some passive islanding detection techniques are discussed as follows:

2.1. Under/Over Voltage and Under/Over Frequency

Under/Over Voltage (UVP/OVP) and Under/Over frequency (UFP/OFP) compares the grid frequency and grid voltage so that they will remain within specified limits imposed by the relevant standards [8]. Under normal working conditions, both the frequency and voltage are maintained in their rated values in order to improve the system stability and reliability.

2.2. Voltage Phase Jump Detection–

Voltage phase transition detector (PJD) method involves checking "sudden phase jump" in the terminal voltage of the inverter and phase difference between the output currents as shown in Fig. 3 [15-20] . This technology is applicable to a current source inverter (CSI) where the phase current and the inverter output voltage is

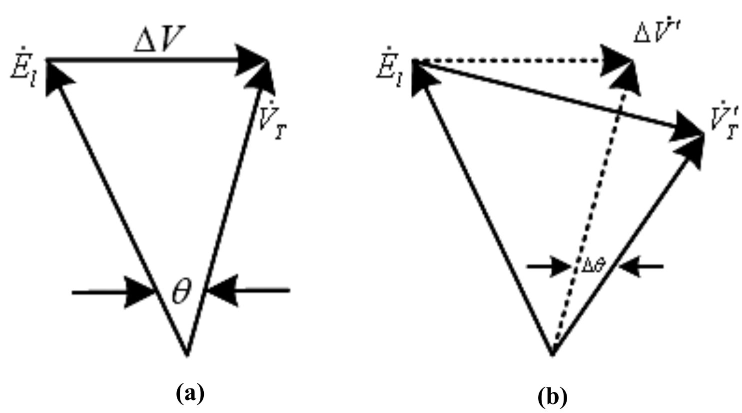

Figure 3: Diagram showing the phase jump detection (a) Before Islanding (b) After Islanding

considered [4]. During the transition from normal mode to the island mode, the phase angle changes suddenly at PCC. The PJD method then search for this sudden phase changes, thereby detecting the island [20]. When the islanding occurred in the inverter, at that moment, the current is reduced to zero [21]. Inverter identifies the condition when the phase error is likely to exceed the standard limit and accordingly activate the controls. The method is very simple and power inverters will not be affected during the transient conditions. This method may not be suitable for islanding detection [22-26] under all operating conditions. The disadvantage of the PJD leads to a failure in detecting islanding in the condition where generated power of DG matches to the local load demand.

2.3. Harmonic Measurement

During islanding conditions, power mismatches between source and load leading to harmonic distortions which is measured by total harmonic distortion (THD). THD is a measure of signal harmonic distortion which is defined as the ratio of the total harmonic component and the fundamental frequency and usually a percentage value [26]. If the monitored parameter exceeds the threshold set value, the inverter should be disconnected from the DG [2]. However, choosing a trip threshold is not easy, because the distortion level of the nonlinear load changes quickly due to it continuous turned on and off [1]. Distribution network under normal operating condition produce lower distortions in terminal voltage whereas, if the island occurs, it will lead to an increase in distortion as well as THD values. If the utility is isolated, impedance of the grid increases and therefore the output current of the inverter create current harmonics as well as voltage harmonics in terminal voltage [25]. Secondly, the harmonics in current of the inverter increases due to the presence of inverter switching process. However, if the system voltage or the inverter output current varies unexpectedly, the detection of islanding may be disrupted. Further, when the power mismatch is not appreciable it may lead to failure in the detection process and thus increases the NDZ leading to unnecessary tripping [27-29]. However, when voltage disturbances occur due to transients in the network, the choice of suitable threshold may be affected and the islanding detection technique fails to identify the disturbance condition [24-25,30-34]. The main idea of this method is based on the combination of the voltage resonant controller and directional control applications. Another algorithm based on the Kalman filter has been proposed to assess the value of the third and fifth harmonic measurements useful for islanding detection [32]. However, this method fails, because of the high quality factor (Q) detection and threshold selection [4].

2.4. Voltage Unbalance

This method monitors three-phase inverter output voltage when load changes and observe voltage unbalance (VU) due to the topology of the network [35]. The three-phase line-to-line voltage is measured during any abnormal load changes, then the magnitude between the phases varies creating voltage unbalance condition. If the mismatch load is large, the number of monitored parameters namely, voltage amplitude, phase, and frequency shift can easily be detected. However, this approach may not be so effective during small changes in load creating relatively lesser power mismatch [39]. It is possible to change the island DG because the distribution network typically includes single-phase loads. In addition, if there is a small change in the load, VU depends upon network conditions [36-37]. The disadvantage of this method is that, VU can be measured in a multiphase system, rather than for single-phase system [28]. A large NDZ, is said to occur in these type of method for islanding detection [28]. The basic idea is to measure the combined unbalanced voltage and current THD with conventional voltage amplitude [2]. It can be concluded that the combination of two or more methods can be highly effective and a small change between the load and generation can be detected which helps in identifying the islanding events [38-40]. The voltage unbalance (VU) may vary because of the change in network topology. Thus, accurate detection of islanding can only occur when the unbalances in the phase voltages are monitored continuously.

3. SOFT COMPUTING AND ADVANCED SIGNAL PROCESSING TECHNIQUES FOR ISLANDING DETECTION

Different soft computing algorithms based human/bird/fish/animal intelligence is popularly used for the detection of islanding in distributed generation system. There are different techniques like Artificial Neural Network (ANN), fuzzy logic control (FLC), and adaptive neuro-fuzzy inference system (ANFIS), particle swarm optimization (PSO), genetic algorithm (GA), support vector machine (SVM), decision tree (DT) Classifier used for islanding detection. The various methods are as shown in Figure 4.

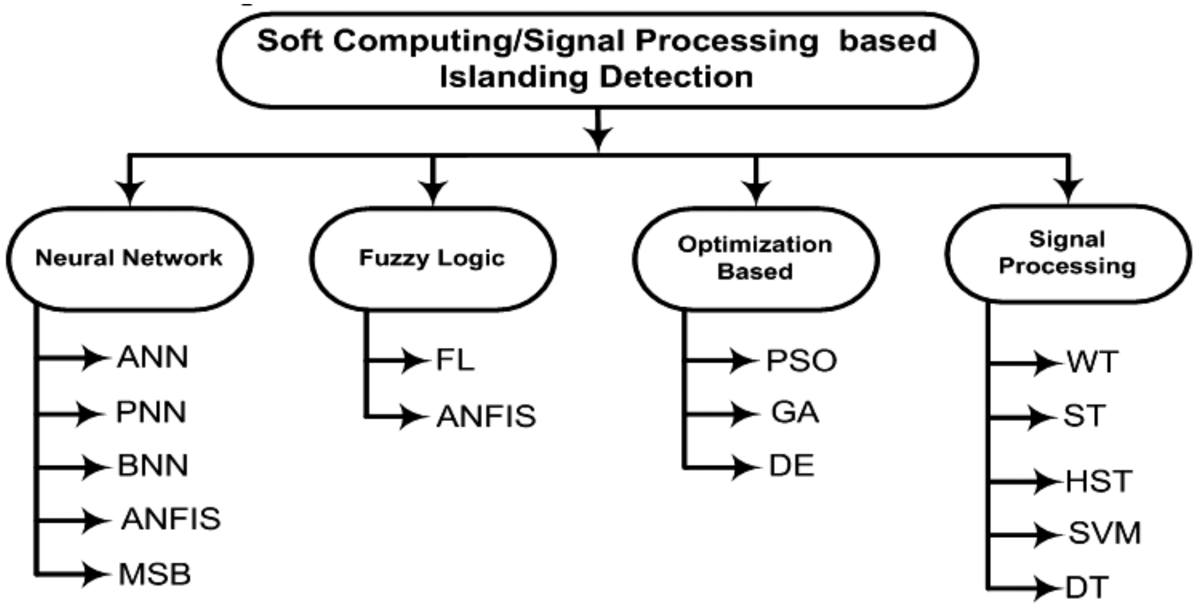

Figure 4: Signal processing and soft computing based methods.

3.1. ANN Based Detection Techniques

Artificial Neural Network (ANN) has a variety of scientific and engineering problems [41] that has been widely used for disturbance detection. Many researchers have applied ANN for islanding detection applications. ANN has been suggested for inverters based DG system [42] and hybrid inverter based DG [43] based on Artificial Neural Network for detection of islanding. Islanding detection based on passive method uses voltage signal [42], three-phase current [43], transient signals etc. as parameters for disturbance analysis. Another suitable islanding detection technique based on hybrid artificial neural network, [44] is suggested based on synchronization of DG. Adapted NN is designed using second order harmonics of the symmetrical components of voltage and currents in doubly-fed wind turbine system for islanding detection [45]. In addition to the neural network, self-organizing map (SOM) neural network, probabilistic neural network (PNN), and modular probabilistic neural network (MPNN) have also been used for islanding detection problem [46-47]. SOM neural networks have been used to distinguish between the island and non- island events. ENN is used for PV based DG system for islanding detection [48]. PNN and MPNN have been used in multi DG system for detection purpose [49-50].

3.2. Fuzzy Logic Based Detection Techniques

Fuzzy logic control (FLC) has shown as a potential methodology for modeling of power systems based on linguistic variables, fuzzy rules, expert human knowledge etc. It is also applied to islanding detection problem. Rotary DG islanding detection technique based on fuzzy logic is proposed in [51]. The technical validation of different types of loads in radial distribution system has been studied to discover islands. The simulation results in that work shows 100 % accuracy for islanding detection. In addition, the implementation of online fuzzy logic control is also designed to study in real-time applications [52-53]. Negative sequence voltage and the negative sequence current techniques are used for the disturbance analysis by some authors. Fuzzy logic is used for distinguishing island and non-islanding events [54]. Sandia frequency shift (SFS) is an active islanding detection method having very small NDZ and is used for inverter based DG systems. Inaccurate tuning of the control gains may lead to the mis-operation of this method. Vahedi and Karrari [55] has studied FLC based control to estimate the circuit parameters and to adaptively adjust SFS to eliminate NDZ. As the works demonstrated excellent performance under various operating conditions and hence suitable for experimental validation.

3.3. ANFIS Based Detection Techniques

ANFIS can be designed as a controller with minimum input and output training data for modeling nonlinear and complex systems effectively. Advantages of both ANN and fuzzy logic control is to improve uncertain capability of learning information. This makes it possible to approximate the nonlinearity and uncertainty of the system, without the need for a pure mathematical model. ANFIS-TS based technique is an effective tool of monitoring power quality and islanding disturbances [56]. The data set from these signals are given input to the ANFIS for training and testing for islanding detection. Thus, ANFIS being easy to implement, fast in detection, can be suitable for hardware implementations. Wavelet transform is used to monitor islanding disturbances using ANFIS [57-59] in inverter based DG systems.

3.4. Decision Tree Based Detection Techniques

Decision Tree (DT) is a data mining approach based on statistical techniques to provide accurate classification of input data. Training ability of this tool is fast in comparison to the other tools for classification objective. In the first step, entire space is used as a root node in decision tree classifier. Initial segmentation using a prediction is made to transform the root node into child nodes. The resolution can be carried out from a child node for more divisions [60]. Detection of islanding methods vastly uses decision tree classifier [61] based on voltage and current signals being passed through DWT to extract the suitable features. These feature data set is given input to decision tree [62] to detect the islanding event. Pham et al. [63] proposed a prototype setup for testing these technologies, and to replace analog electronics in order to achieve low-cost feature extraction. However, powerful digital signal processing (DSP) hardware is available for implementation of the algorithms for disturbance analysis. The merit of the proposed method is to optimize the island relay threshold setting, which allows the minimum detection area in islanding operation under different working scenarios and for various configurations.

Table 1
Comparison of Islanding Detection Time.

Sl no	*Technique*	*Islanding Detection Time (in sec)*
1.	CWT	0.8
2.	DWT	0.050
3.	FLC	0.070
4.	ANN	0.075
5.	ANFIS	0.062
6.	SVM	0.040
7.	DT	0.041

Table 2
Comparison of Passive Islanding Techniques

Method	*Implementation Speed*	*Weakness*	*Merits*
O/U voltage and frequency protection	Easy to implement but reaction time is unpredictable and variable	Very large NDZ	Comparing the P-V and P-Q characteristics of the controlled constant current inverters
Voltage PJD	Difficult to implement and hard to select threshold that provides reliability	Islanding is not detected, generating a local load power demand DG match	Controlled by using a PLL
Harmonics Measurements	Easy to implement but difficult to choose threshold	Failure to detect islanding condition in cases of low distortion of voltage and output current or high quality load	Easier to identify islanding in comparison to PQ.
Voltage Unbalance	Easy to implement based on voltage variation and selection of threshold	Does not apply to the phase of the signal system	Combining two or more methods (VU and THD)

4. CONCLUSION

In this paper, different islanding detection techniques are being discussed thoroughly. Firstly different techniques based on active, passive and hybrids are being discussed and a comparative analysis is presented. Further advanced signal processing and soft computing methods are discussed in brief and are compared with conventional methods to highlight the advantages of these methods for detection of islanding disturbances. These methods have faster detection time and minimum NDZ.

REFERENCES

[1] A. Khamis, H. Shareef, E. Bizkevelci, T. Khatib, "A review of islanding detection techniques for renewable distributed generation syatems", pp.483-493, 2013.

[2] A. Aljankawey, W. Morsi, L. Chang, C. Diduch, "Passive method-based islanding detection of renewable-based distributed generation: the issues", IEEE Electrical Power & Energy Conference, pp. 1-8,2010.

[3] P. Mahat, B. Bak-Jensen, "Review of islanding detection methods for distributed generation", Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 2743-2748, 2008.

[4] R. Kunte, W. Gao, "Comparison and review of Islanding detection techniques for distributed energy resources", 40th North American power symposium, pp. 1-8, 2008.

[5] M. Moradzadeh, M. Rajabzadeh, M. Bathaee, A. Novel, "Hybrid islanding detection method for distributed generations", Third International Conference on electric utility deregulation and restructuring and power technologies, pp. 2290-2295, 2008.

[6] H. Zeineldin, E. El-Saadany, M. Salama, "Impact of DG interface control on islanding detection and non-detection zones", IEEE Transactions on Power Delivery, pp. 1515-23, 2006.

[7] M. E Ropp, M. Begovic, A. Rohatgi, G.A Kern, R. H Bonn, and S.Gonzalez, "Determining the relative effectiveness of islanding detectionmethods using phase criteria and non detection zones", IEEE Trans.Energy Conversion, Volume 15, Issue 3, pp. 290-296, Sep 2000.

[8] A. Timbus, A.Oudalov, C. Ho, "Islanding detection in smart grids", Energy Conversion Congress and Exposition (ECCE), pp. 3631-3637,2010.

[9] Recommended Practice for Utility Interconnected Photovoltaic (PV)Systems, IEEE Standard, pp. 929-2000, 2000.

[10] H. Zeineldin, M. Salama, "Impact of load frequency dependence on the NDZ and performance of the SFS islanding detection method", IEEE Transaction on Industrial Electronics, pp. 139-46, 2011.

[11] C. Yoo, D. Jang, S. Han, D. Oh, S. Hong, "A new phase drift anti-islanding method for grid-connected inverter system", Eighth international conference on power electronics-ECCE Asia, pp. 902-906, 2011.

[12] P. Li, Y Sheng, L Zhang, X. Yang, Y. Zhao, "A novel active islanding detection method based on current-disturbing", Electrical Machinesand Systems, pp. 1-5, 2009.

[13] S. Lee, J. Park, "New islanding detection method for inverter-based distributed generation considering its switching frequency", IEEE Transaction on Industry Applications, pp. 2089-98, 2010.

[14] B. Yu, M. Matsui, G. Yu, "A correlation based islanding detection method using current magnitude disturbance for PV system", IEEE Transaction on Industrial Electronics, pp. 2935-43, 2010.

[15] S. P. Chowdhury, S. Chowdhury, and P. A. Crossley, "Islandingprotection of active distribution networks with renewable distributedgenerators; a comprehensive survey", Electric Power Systems Research,Volume 79, Issue 6, pp. 984-992, June 2009.

[16] [16]Y. Zhihong, A. Kolwalkar, Z. Yu, D. Pengwei, and W. Reigh,"Evaluation of anti-islanding schemes based on non-detection zoneconcept", IEEE Trans. Power Electronics, Volume 19, Issue5, pp.1171-1176, September 2004.

[17] H. Kobayashi, K. Takgawa, "Statistic Evaluation of optimum islandingpreventing methods for utility interactive small scale".The first IEEEworld conference on photovoltaic energy conversation, Volume 1,pp.1085-1088, 1994.

[18] M. Shi, Z. Wu, and X Xu, "Detection of Voltage Variation Signal Basedon Double Wavelet", in Proc. of the Sixth International ConferenceIntelligent Systems Design and Applications, Volume: 2, pp. 730-733,2006.

[19] I. Balaguer-alvarez, E. Ortiz-rivera, "Survey of distributed generation islanding detection methods", IEEE Latin America Transactions, pp. 565-70, 2010.

[20] W. Teoh, C. Tan, "An overview of islanding detection methods in photovoltaic systems", World Academy of Science Engineering and Technology, pp. 674-82, 2011.

[21] W. Hu, Y, Sun, "A compound scheme of islanding detection according to inverter", Asia-Pacific power and energy engineering conference, pp. 1-4, 2009.

[22] W. Xu, K. Mauch, and S. Martel, "An Assessment of DistributedGeneration Islanding Detection Methods and Issues for Canada", CETC-Varennes2004-074, July 2004.

[23] D. M. Laverty, D. J. Morrow, R. J. Best, and P. A. Crossley,"Differential ROCOF relay for Loss-of-Mains protection of RenewableGeneration using phasor measurement over Internet Protocol",Integration of Wide-Scale Renewable Resources Into the PowerDelivery System, pp.1-1, 2009.

[24] B. Singam, and L.Y Hui, "Assessing SMS and PJD Schemes of Anti-Islanding with Varying Quality Factor", in Proc. of the IEEEInternational Power and Energy Conference, pp. 196-201, 2006.

[25] GA. Yin, "Distributed generation islanding detection method based on artificial immune system", IEEE/PES transmission & distribution conference & exposition: Asia and Pacific, pp. 1-4, 2005.

[26] Ackermann, Andersson and Soder (2000) "ElectricityMarket Regulations and their Impact on DistributedGeneration", Electric Utility Deregulation and Restructuring and Power Technology, Proceeding, DRPT 2000,International Conference. UK: London,2000

[27] W. Bower and M. Ropp."Evaluation of islanding detection methods forphotovoltaic utility interactive power systems", Report IEA-PVPS T5-09, 2002.

[28] J. Sung-Il, and K. Kwang-Ho,"Anew Islanding Detection algorithm fordistributed generations interconnected with utility networks", EightIEEE conference in power system protection, Volume 2. pp. 571-574,2004.

[29] J. Sung-Il, and K. Kwang-Ho, "An islanding detection method fordistributed generations using voltage unbalance and total harmonicdistortion of current", Power Delivery, IEEE Trans. Volume 19, Issue 2, pp.745- 752,April 2004.

[30] P. Mahat, Z. Chen, and B. Bak-Jensen, "Review of islanding detectionmethods for distributed generation", in Proc. of Electric UtilityDeregulation and Restructuring and Power Technologies, DRPT 2008,Third International Conference, pp.2743-2748 on 6-9 April 2008.

[31] C. Hsieh, J. Lin, and S. Huang, "Enhancement of islanding-detection ofdistributed generation systems via wavelet transform-

based approaches",International Journal of Electrical Power & Energy Systems, Volume30, Issue 10, pp. 575-580, December 2008.

[32] Velasco, D., et al., "Review of anti-islanding techniques in distributedgenerators". Renewable and Sustainable Energy Reviews. vol.4(6): pp.1608-1614,2010.

[33] Kobayashi, H., et al. Method for preventing islanding phenomenon onutility grid with a number of small scale PV systems. inPhotovoltaicSpecialists Conference, 1991., Conference Record of the Twenty SecondIEEE. 1991.

[34] Liserre, M., et al., "An Anti-Islanding Method for Single-Phase InvertersBased on a Grid Voltage SensorlessControl.",IndustrialElectronics,IEEE Transactions on, vol.53(5), pp. 1418-1426, 2006

[35] S. I. Jang and K. H. Kim, "An islanding detection method for distributedgenerations using voltage unbalance and total harmonic distortion ofcurrent," IEEE Trans. Power Del., vol. 19, no. 2, pp. 745-752, Apr.2004.

[36] S. I. Jang, and K. H. Kim, "A new islanding detection algorithm fordistributed generations interconnected with utility networks," in Proc.IEE International Conference on Developments in Power SystemProtection, vol.2, pp. 571-574, April 2004.

[37] S. I. Jang, and K. H. Kim, "An islanding detection method fordistributed generations using voltage unbalance and total harmonicdistortion of current," IEEE Tran. Power Delivery, vol. 19, no. 2, pp.745-752, April 2004.

[38] F. De Mango, M. Liserre, A. D. Aquila, and A. Pigazo, "Overview ofAnti-Islanding Algorithms for PV Systems. Part I: Passive Methods",12th International, pp. 1878-1883, 2006.

[39] V. Kaura, and V. Blasko, "Operation of a phase locked loop systemunder distorted utility conditions," IEEE Trans. Ind. Applica., vol. 33,pp. 58-63, January 1997.

[40] M. A. Eltawil, and Z. Zhao, "Grid-connected photovoltaic powersystems: Technical and potential problems-A review", Renewable andSustainable Energy Reviews, Volume 14, Issue 1, pp. 112-129. January2010.

[41] Dias FM, Antunes A, Mota AM. Artificial neural networks: a review ofcommercial hardware. Eng Appl Artif Intel, vol.17,pp.945–52, 2004.

[42] Fayyad Y, Osman A. Neuro-wavelet based islanding detection technique. In: IEEE electric power and energy conference, pp. 1–6, 2010.

[43] ElNozahy MS, El-Saadany EF, Salama MMA. A robust wavelet-ANN based technique for islanding detection. In: IEEE power and energy society general meeting, pp. 1–8, 2011.

[44] Ghazi R, Lotfi N. A new hybrid intelligent based approach to islanding detection in distributed generation. In: Int universities power engineering

[45] Abd-Elkader AG, Allam DF, Tageldin E. Islanding detection method for DFIG wind turbines using artificial neural networks. Int J Electr Power, vol. 62, pp.335–43, 2014.

[46] Moeini A, Darabi A, Karimi M. Clustering governor signal of distributed generation for islanding detection. In: IEEE conf on computational tech in electrical and electronics engineering,pp. 493–8, 2014.

[47] Moeini A, Darabi A, Rafiei SMR, Karimi M. Intelligent islanding detection of a synchronous distributed generation using governor signal clustering. Electr Power Syst Res vol. 81, pp.608–16, 2011.

[48] Chao K-H, Chiu C-L, Li C-J, Chang Y-C. A novel neural network with simple learning algorithm for islanding phenomenon detection of photovoltaic systems. Exp Syst Appl, vol. 38, pp. 12107–15, 2011.

[49] Lidula NWA, Rajapakse AD. Fast and reliable detection of power islands using transient signals. In: Int conf on industrial and information systems; 2009. pp. 493–8.

[50] Mohanty SR, Ray PK, Kishor N, Panigrahi BK. Classification of disturbances in hybrid DG system using modular PNN and SVM. Int J Electr Power, vol. 44, pp.764–77, 2013.

[51] Rosolowski Eugeniusz, Arkadiusz Burek, Leszek Jedut. A new method for islanding detection in distributed generation. Wroclaw University of Technology, Department of Electrical Power Engineering, Poland; 2007.

[52] Samantaray SR, El-Arroudi K, Joos G, Kamwa I. A fuzzy rule-based approach for islanding detection in distributed generation. IEEE Trans Power Deliver, vol. 25, pp.1427–33, 2010.

[53] Kumarswamy I, Sandipamu TK, Prasanth V. Analysis of islanding detection in distributed generation using fuzzy logic technique. 7th Asia modelling symposium, pp. 3–7, 2013.

[54] Dash PK, Padhee M, Panigrahi TK. A hybrid time–frequency approach based fuzzy logic system for power island detection in grid connected distributed generation. Int J Electr Power, vol.42 pp. 453–64, 2012.

[55] Vahedi H, Karrari M. Adaptive fuzzy sandia frequency-shift method for islanding protection of inverter-based distributed generation. IEEE Trans Power Deliver, vol. 28, pp.84–92, 2013.

[56] Bitaraf H, Sheikholeslamzadeh M, Ranjbar AM, Mozafari B. Neuro-fuzzy islanding detection in distributed generation. IEEE innovative smart grid technologies; 2012.pp. 1–5.

[57] Faa-Jeng L, Kuang-Hsiung T, Jian-Hsing C. Active islanding detection method using wavelet fuzzy neural network. In: IEEE int conf on fuzzy systems; 2012. pp. 1–8.

[58] Faa-Jeng L, Yi-Sheng H, Kuang-Hsiung T, Jian-Hsing C, Yung-Ruei C. Active islanding detection method using d-axis disturbance signal injection with intelligent control. IET Gener Trans Distrib, vol 7, pp. 537–50, 2013.

[59] Hashemi F, Ghadimi N, Sobhani B. Islanding detection for inverter-based DG coupled with using an adaptive neuro-fuzzy inference system. Int J Electr Power, vol.45, pp.443–55, 2013.

[60] Rokach L, Maimon O. Top-down induction of decision trees classifiers - a survey. IEEE Trans Syst Man Cybernetics Part C Appl Rev , vol. 35, pp.476–87, 2005.

[61] Heidari M, Seifossadat G, Razaz M. Application of decision tree and discrete wavelet transform for an optimized intelligent-based islanding detection.

[62] Lidula NWA, Rajapakse AD. A pattern recognition approach for detecting power islands using transient signals—Part I: Design and implementation. IEEE Trans Power Deliver 2010;25:3070–7.

[63] Pham JP, Denboer N, Lidula NWA, Perera N, Rajapakse AD. Hardware implementation of an islanding detection approach based on current and voltage transients. In: IEEE electrical power and energy conference; 2011. p. 152–7.

[64] El-Arroudi K, Joos G. Data mining approach to threshold settings of islanding relays in distributed generation. IEEE Trans Power Syst vol. 22, pp.1112–9, 2007.