2015 IEEE Power, Communication and Information Technology Conference (PCITC)
Siksha 'O' Anusandhan University, Bhubaneswar, India.

A Novel Islanding Detection Technique Based on Wavelet Packet Transform

M.Mishra, P.K .Rout , S.Patel
Electrical and Electronics Engineering Department
ITER, S'O'A University
Bhubaneswar, Odisha, India
Manohar2006mishra@gmail.com

Abstract— **In this manuscript, wavelet packet transforms (WPT) based method is proposed for detection of the islanding condition in the distribution system with distributed generation (DG).The system consist of DG sources like hydro turbine generator with synchronous machine and wind turbine generator with asynchronous machine. Negative sequence component based assessment of fault condition is considered here. A new feature index named Change of energy at different node are calculated using WPT for various islanding and non-islanding fault cases which are very often occurred practically like capacitor switching, load rejection , line to line fault ,three phase fault, voltage sag and swell etc.. The obtained simulated results show the proposed technique is found to be highly effective for discriminate islanding events under a wide range of operating conditions from other type of disturbances in the power distribution network. The proposed scheme are fully analyzed by extensive MATLAB simulation study.**

Keywords- Negative sequence components; Wavelet transform (WT); Islanding; WPT

I. INTRODUCTION

The most common alternatives for electric power generation in today's world are DGs. DGs stand for Distributed generation which means small scale power generation. Several types of DGs such as (photovoltaic (PV), fuel cells, micro hydro turbines, small wind turbines, and additional equipments that are supplied biomass or geothermal energies) can be used for generating energy. To reduce the amount of electricity loss, DGs are located nearer to the loads. So that it can reduce the size and number of power lines [1].

DGs are generally used because of several advantages such as

- Ability to improve the power system efficiency.
- Increased the power system reliability and reduced the transmission line losses.
- Upgrade the system flexibility.
- Environmental benefit.

But DGs have some disadvantages such as Islanding detection, known as the most common drawbacks of DGs.

'Islanding' is simply known as that type of condition in which the utility system that contain both distribution generation and load remains energized while it is disconnected or electrically isolated from the main source (grid source). According to IEEE 1547-2003, the isolation time should be less than 2 Sec if islanding occurred [2]. Meanwhile islanding is divided into two categories, such as Intentional islanding and Unintentional islanding. Intentional islanding is occurred during fault condition which can be easily detected and remove by disconnected the main grid from the utility system. But the main problem arises when Unintentional islanding occurred. Due to this condition several problems may arise, such as power quality problems to the customers, safety hazard to the personnel, voltage and frequency instability and may cause damage to the power generation and power supply equipments. Thus islanding detection is necessary to avoid such type of problems [2].

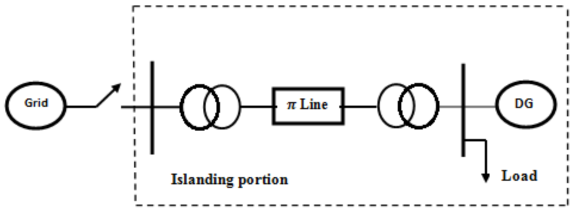


Figure 1. Illustration of islanding condition including a DG source.

As for now two types of detection technique has been invented that is local detection technique and remote detection technique. Local detection technique is used to measure data from the DG side, so it is based on DG side. But Remote detection technique is used to measure data from the utility side, so it is based on the utility side. Remote detection technique is based on the communication between the utility system and DGs. It has more efficient than local detection technique, but it is too expensive to implement than local detection technique, thus for islanding detection we generally used local detection technique. The Local detection technique is broadly classified into three types, such as Passive detection technique [3-7], Active detection technique [8-12] and Hybrid detection technique[13-15]. According to their NDZ (non-detection zone), the performance of each detection technique can be evaluated. NDZ is that type of zone in which the islanding detection technique has failed to detect islanding condition [2,16].

The Passive detection technique is monitored on the basis of system parameters like voltage, current, frequency and harmonic distortion on the DG site at the point of common coupling (PCC) with the utility grid and compared with a predetermined value called as threshold value. During islanding condition these parameters are very high. The injection of small periodic disturbances into the system grid, in terms of voltage and frequency are called as Active detection technique. The change in the system parameters is going to be maximized when the DG is islanded, but when the DG is connected to the grid, the change will be negligible. Hybrid detection technique is the conjunction of both Passive detection technique and Active detection technique.

In most case passive detection technique is generally used as compare to active detection technique because it has low cost, but the efficiency of these types of technique is too poor because of their larger non-detection zone. Active detection technique has smaller non-detection zone, but the introduction of small periodic disturbances is the major disadvantages of such type of technique. Thus further research work is going on to develop a new Hybrid detection technique which has smaller non-detection zone with greater efficiency [17,18].

In this paper, a newly introduced Wavelet Packet Transform (WPT) is used to detect the islanding operation of the simplified synchronous machine (DG1) and Asynchronous machine (DG2). It is more reliable as compare to Discrete Wavelet transform (DWT) and Continuous Wavelet transform (CWT) because the WPT is provide more depth view of frequency and time variation during the analyzed process. But DWT merged different types of frequency generally at high frequencies and hiding much important information. All though CWT is produced much more coefficients than needed, therefore, its computational efficiency is less as compared to both the above method WPT and DWT.

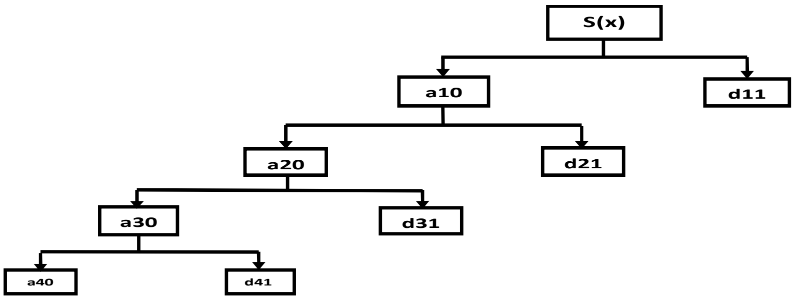
The major contribution and novelty of this study as follows:

- Two different types of synchronous based DG as mentioned above as hydro turbine and governor system with a synchronous generator (DG1) and another is a wind turbine with asynchronous generator (DG2) are consider in the test model.
- WPT is used for islanding detection instead of DWT due to its better time and frequency localization. The characteristics of WPT poses better time localization at a higher frequency level.

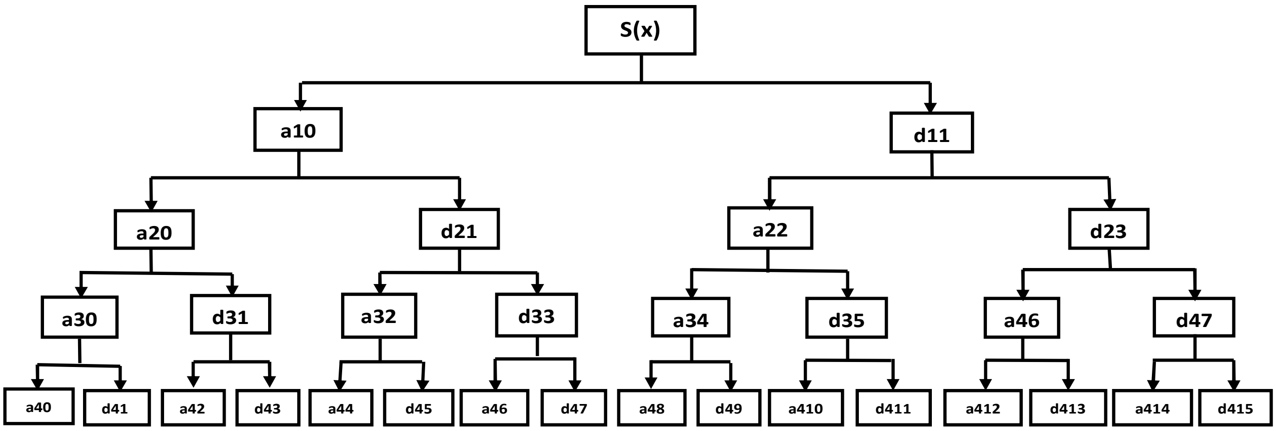
The rest of this paper is organized in the following order. Section II represents the Wavelet Packet Transform (WPT), meanwhile Section III is the Evaluation part which is the combination of Model description part, System data part and Case studies part respectively. Section IV described the result of the simulated system and the last part will be the conclusion part which is described in section V. Below the conclusion part, the Flowchart is given based on Wavelet Packet transform (WPT).

II. WAVELET PACKET TRANSFORM (WPT)

The word "Wavelet" has discovered from a French origin word "ondelette" which means a small wave. If an arbitrary function $S(x)$ is considered for wavelet analysis, then baby wavelets at different versions of S(x) are obtained by the process of translation and compression (dilation). In the next step when these wavelets are



(a)



(b)

Figure 2.4th level decomposition tree(a) WT (b) WPT frequency and time leads to Continuous Wavelet Transform(CWT). When the mother wavelet is dilated and translated discretely then this is known as discrete wavelet transform(DWT). In DWT the bandwidth at low frequencies is smaller than the higher frequencies which affect the process of feature extraction of the signal component at a certain level of high frequencies [19-20].

To avoid such types of problem and for better frequency resolution the decomposition process is carried out by decomposing both detail and approximate coefficient simultaneously at each level. This process is called as Wavelet Packet Transform (WPT).. The upper level of WPT gives better time resolution; whereas the lower level gives better frequency resolution.

The original signal is decomposed to 'n' level as shown in figure 2 for WT and WPT respectively. The signal can be represented as (a10,d11),(a20,d21,d11),(a30,d31,d21,d11) for WT. On the other case ,the original signal can be decomposed to 2^n node like a40, d41, a42, d43, a44, d45, a46, d47, a48, d49, a410, d411,a412,d413,a414,d415.So WPT provides better frequency resolution and control of features then WT. Mathematically, the orthogonal decomposition of the given function $S^n(x)$ can be stated as:

$$S_{i,j}^n(x) = 2^{-i/2} S^n\left(2^{-i}x - j\right) \quad (1)$$

Where $n = 0,1,2....,\left(2^{-i} - 1\right)$ is represented as the frequency parameter (node number) and 'i' is level of decomposition (depth of parameter) in the wavelet packet tree. Here 'j' denotes the position parameter (sampling time), that belongs to the set of integer number.
The total energy of the signal can be calculated as

$$E_j = \sum_{k=-\infty}^{\infty} \left|WPTcoff_j(k)\right|^2 \quad (2)$$

Where WPTcoff is the WPT coefficient for node j.
Change of energy index (COEI) for different node is found out by the following expression

$$COEI_j = E_{fj} - E_{Aj} \quad (3)$$

Where E_{fj} the total energy is for one cycle ahead of fault inception and E_{Aj} is the total energy for one cycle before the inception of the fault.

III. SYSTEM STUDIED

In this paper, to investigate the proposed methods a multi DG radial distribution system is considered as shown in Figure 3. Two number of DGs one as hydro turbine and governor system with a synchronous generator (DG1) and another is wind turbine with asynchronous generator (DG2), connected to the grid through point of common coupling (PCC).

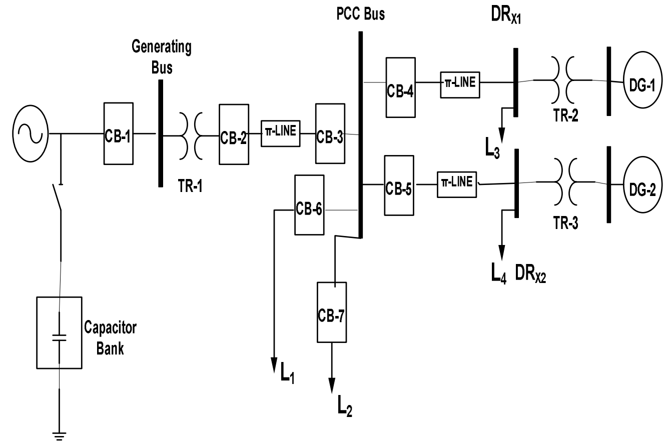


Figure 3. The single line diagram of the studied Power Distribution system with multiple Distributed generating system (DGs).

The DG1 consist of 10 MW synchronous generator connected to a 79 KV grid through a 30 KM, 13KV feeder and DG2 consist of 1.5 MW asynchronous generator driven by wind turbine connected to a 79 KV grid through a 30 KM, 13 KV feeder. Two loads L1 and L2 are connected to the PCC bus. The details of the generator, transformers, DGs, distribution lines and loads are mentioned in Table 3 of Appendix. The relays are placed at the DG end to collect the voltage/current signal for both islanding and non-islanding conditions. The sampling frequency of the system studied is 3.8 kHz having 64 numbers of samples in one cycle on the 60 Hz base frequency. The voltage and current signals are extracted at the targeted DG (DG-1, DG-2).

IV. EVALUATION

A. Case Studies:

Here total nine numbers of different cases are considered including islanding events as listed in Table 1. The first case is the islanding condition in which the grid source is disconnected from the DGs by opening the circuit breaker (CB1). The next three cases (case 2, case 3 and case 4) are dealing with fault condition. In this simulated diagram, we introduce a three phase fault nearer to the general bus with circuit breaker CB1 is closed. Case 5 is considered to be the effect of sudden load change where we connect L3 and L4 by closing and opening of the circuit breakers. Case 6 and Case 7 represents the voltage sag and swells condition respectively. According to table 1, Case 8 is denoted for the tripping of one of the DG other than targeted DG. The last case is the Capacitor switching case.

B. Result and Discussions:

For each of nine cases as described above the three phase voltages are extracted at the targeted DG location. Then these voltage signals are passed through the sequence analyzer to extract the negative sequence component. Negative sequence voltage components are carried out for all the nine cases.

Table 1
Different types of case studies including islanding case

Case number	Types of Cases
C1	Islanding condition
C2	Single-line to ground fault
C3	Three-phase fault
C4	Line to line fault
C5	Sudden load change
C6	Voltage sag
C7	Voltage swell
C8	Tripping of one DG
C9	Capacitor switching

For the simulation purposed we have considered sampling frequency of 3.8 kHz and system frequency is 60 Hz. Four level of decomposition are carried out by WPT, which provide sixteen nodes in the Wavelet decomposition tree. The sub-band ensure a frequency bandwidth of 120 Hz which is closer to fundamental frequency of 60HZ.Daubechies 10 (db10) is used as mother wavelet to perform this analysis because of good performance compared to other wavelet function.

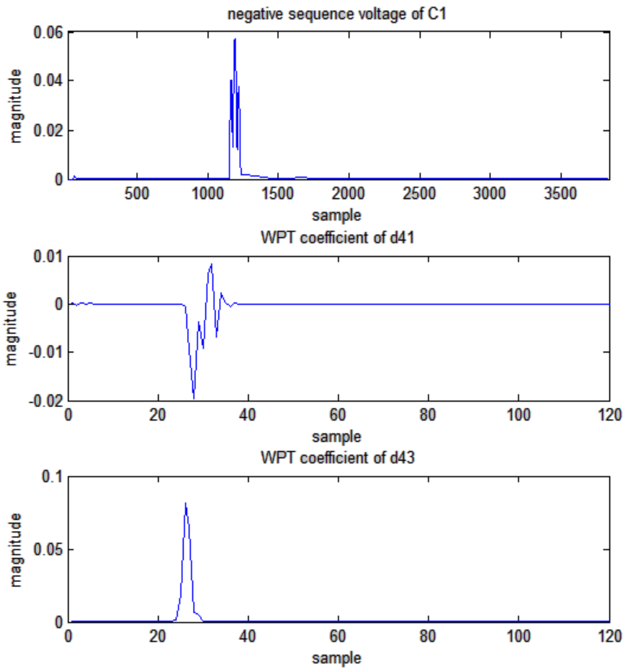


Figure 4. Voltage signal for islanding case C1(a)Negative sequence voltage (b)WPT coefficient at node two (c) WPT coefficient at node four.

Figs. 4(a)-7(a) show the negative sequence voltage signal for islanding case(C1),Three phase fault case(C3)and sudden load change case (C5) and voltage sag case(C7) respectively.Fig.4 (b)-Fig.7(b) indicate the WPT coefficient at node four for case C1,C3, C5 and C7 respectively. In the same way the coefficient for node two are shown in Fig. 4(c)-Fig7(c). The same observations are also analyzed for other cases and the results are not shown in this paper due to space limitations. The result indicate that for both the coefficient for node four and node two are highly identifiable under islanding case from other non islanding cases.

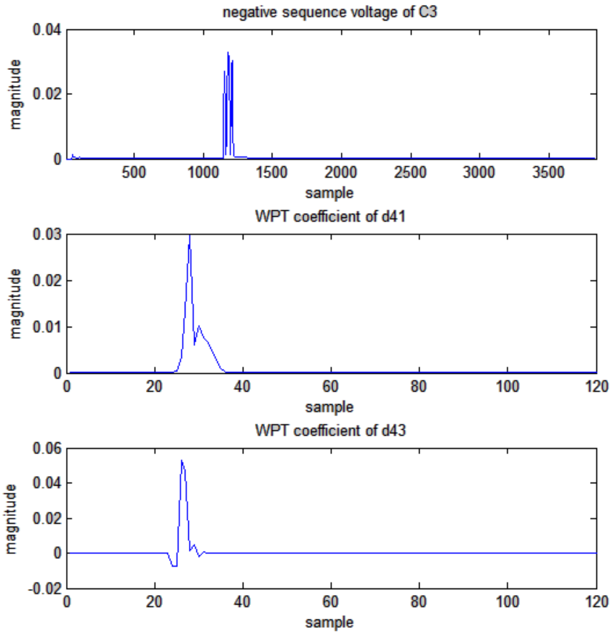


Figure 5. Voltage signal for case C3(a)Negative sequence voltage (b)WPT coefficient at node two (c) WPT coefficient at node four.

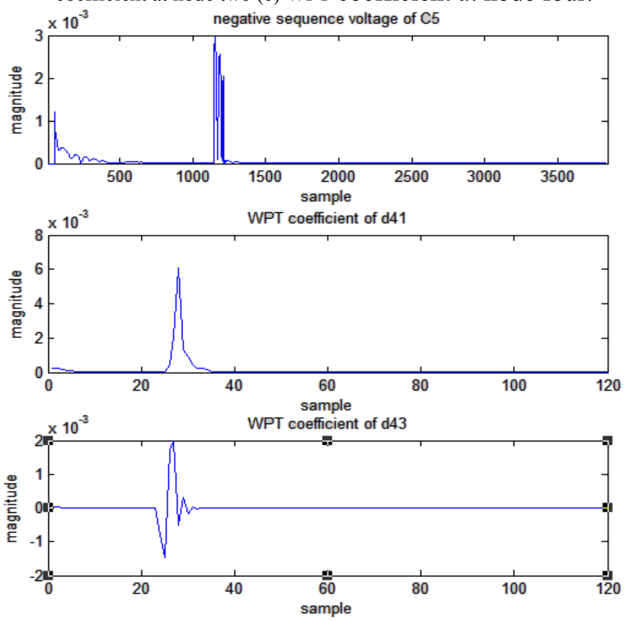


Figure 6. Voltage signal for islanding case C5(a)Negative sequence voltage (b)WPT coefficient at node two (c) WPT coefficient at node four

Fig.8 and 9 show the change of energy index (COEI) at each node (node four and two) respectively. The change of energy index has been attenuated in the rest of the nodes, so they are not shown in result. 100 number of data are generated by changing the active power mismatch up to 40% and reactive power mismatch up to 5 % for islanding case C1, changing fault resistance 0 to 200 Ω for case C2, C3 and C4, changing load parameter for case C5, 10 to 80% sag for case C6 10 to 80 % swell for case C7, and capacitor switching from 0.5MVar to 10 MVar case C9

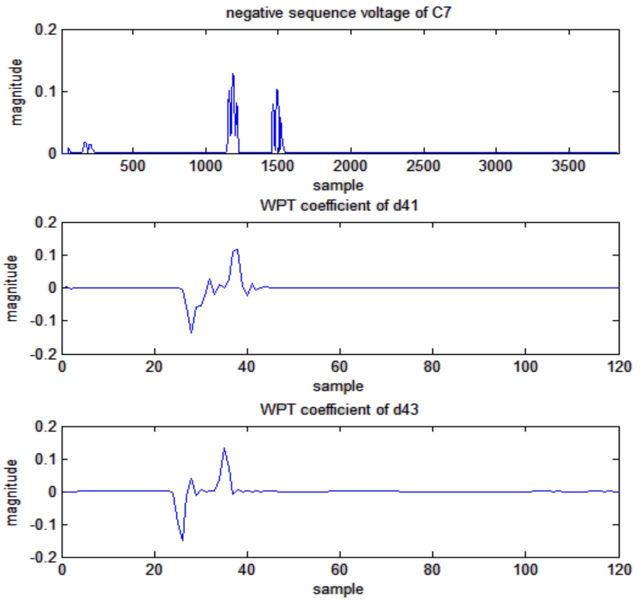


Figure 7. Voltage signal for islanding case C7(a)Negative sequence voltage (b)WPT coefficient at node two (c) WPT coefficient at node four.

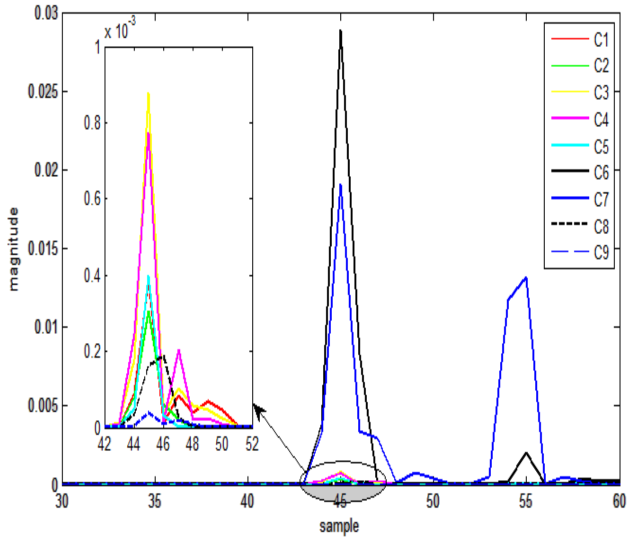


Figure 8. Change of energy index at node four

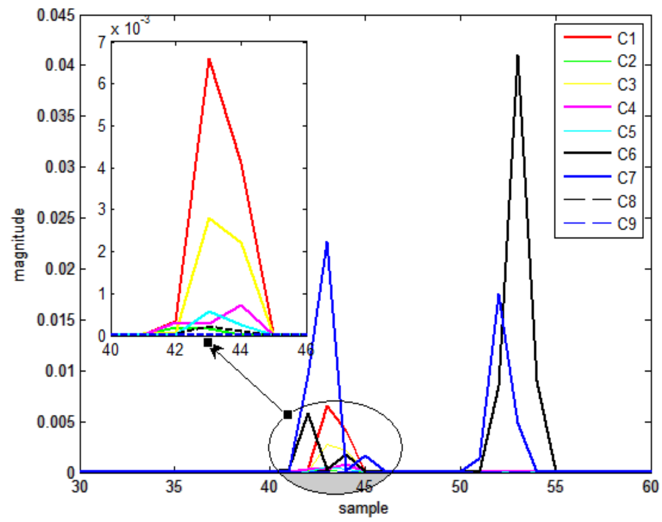


Figure 9.change of energy index at node two

Table 2

Change of energy index for node four and two at target location DG1

Cases	COEI at node Four		COEI at node Two	
	Max	Min	Max	Min
C1	0.010404	0.007206	0.000385	0.000353
C2	0.002864	8.14 x e-6	0.000613	1.81 x e-5
C3	0.005154	0.000232	0.016581	1.12 xe-5
C4	0.003038	5.61 x e-5	0.005539	2.83 xe-5
C5	0.000575	1.73 x e-5	0.0004	2.99 x e-5
C6	0.037167	0.006238	0.025119	0.00564
C7	0.040971	0.007246	0.028851	0.005222
C8	0.000225	3.19 x e-6	0.000188	8.75 x e-7
C9	2.55 x e-6	2.48 x e-7	3.93 x e-5	7.34 x e-7

Maximum and minimum values of COEI at node four and two for different case at target DG location DG2 bus are shown in Table 2. Table 2 clearly indicate the COEI for islanding case C1 is always a higher value compared to other cases except voltage sag case C6 and voltage swell case C7 .So by checking the same change of energy index at node two the index value for islanding case is smaller from case C7.Based on the above analysis a threshold value for node four is chosen as 0.007 and for node two is to be 0.005.The complete flowchart for the proposed method is shown in Fig. 10.

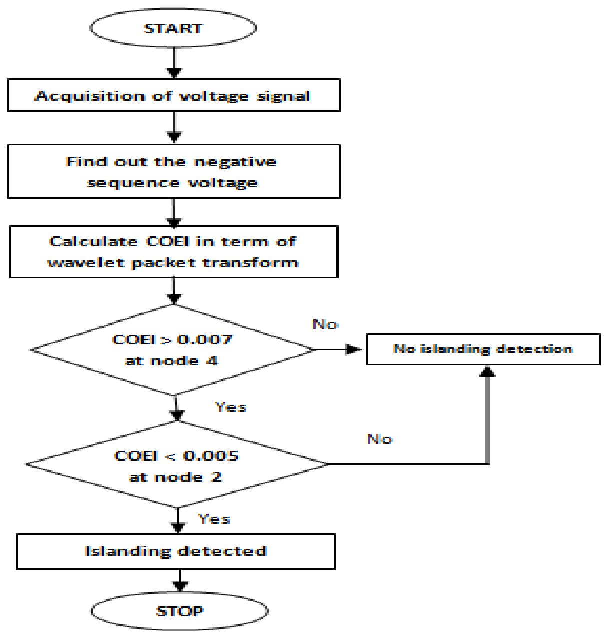


Figure 10. Flow chart of the proposed method for islanding detection

V. CONCLUSION

This paper presents an islanding detection technique based on change of energy index at DG location. By the used of Wavelet Packet Transform (WPT), some valuable information about change of energy is extracted in time-frequency domain. This paper considered nine numbers of cases including islanding case for analyzing the proposed method. Here an islanding can easily identified by checking the COEI at node four and two. If COEI is greater than the threshold (0.007 determined in this paper) then this is an islanding or voltage swell case. Again to discriminate the islanding and voltage swell case the same index is checked for node two where, if COEI is lesser than (0.005 in this study) then this is an islanding case. This method is characterized by its simplicity and computationally efficient because it is based on a single index and therefore the burden to the processor is avoided without affecting the performance of result. The concept can be applied in real time application through Digital signal processor kit and advanced interfacing devices in future.

Appendix

Table 3 Studied system data (Figure 3)

System Elements	Model Parameter	Values			**System Elements**	Model Parameter	Values
Source data (Generator)	Rated power	100 MVA			DG1 (HTG) Generator of DG1:*simplified synchronous machine*	Rated power	10 MVA
	Rated Voltage	79 KV				Rated Voltage	13 KV
	Base Voltage	79 KV				Inertia Const(pu)	inf
	Frequency	60 (Hz)				Internal resistance	0.01466 Pu
Transformer data (TR1,TR2,TR3)		TR1	TR2	TR3		Reactance (pu)	0.22
	Rated Voltage (KV)	79/13 ,(Dyn1)	13/13 ,(Dyn1)	0.4/13 ,(Dyn1)	DG2 (Wind Turbine) Generator of DG2:*asynchronous machine*	Rated MVA	1.5
						Rated KV	0.4
	Rated (MVA)	28	10	10		Inertia Const(pu)	0.48
	Frequency(Hz)	60 Hz	60 Hz	60 Hz		Frequency(Hz)	60
	(R1&R2) (pu)	0.00375 pu	0.00375 pu	0.00375 pu		Stator resistance,R_s (pu)	0.016
	(L1&L2) (pu)	0.1 (pu)	0.1 (pu)	0.1 (pu)		Rotor resistance,R_r (pu)	0.015
	Magnetizing inductance (Xm) pu	500 pu	500 pu	500 pu		Stator inductance,L_s (pu)	0.017
Transmission Line data (pi line) TL1:20km TR2:30km TR3:30km	R_0 (Ω/km)	0.0424				Rotor inductance,L_r (pu)	0.156
	R_1 (Ω/km)	0.0135					
	X_0 (H/km)	1.39e-4				Mutual inductance, L_m (pu)	3.5
	X_1(H/km)	4.9869e-5					
	C_o (F/km)	5.01e-9			Normal Loading Data DG1 bus load L3:	Active power(MW)	3.8
	C_1 (F/km)	11.33e-9				Reactive power(MVAr)	2
Normal Loading Data PCC bus load L1:	Active power(MW)	4.7			PCC bus load L2 and L4	Active power(MW)	4.7 0.75
	Reactive power(MVAr)	1.8				Reactive power(MVAr)	1.8 0.415

REFERENCES

[1] G. Ahmad ,D Allam, E. Tageldin, "Islanding detection method for DFIG wind turbines using artificial neural Networks", international journal of Electrical power and energy systems,vol.62,pp-335-343,may 2014

[2] A.Khamis, H.Shareef, E.Bizkevelci and T.Khatib, "A review of islanding detection techniques for renewable distributed generation systems", Renewable and Sustainable Energy Reviews,vol.28,pp-483-493,2008.

[3] M.A. Redfern and O.Usta, "A new microprocessor based islanding protection algorithm for dispersed storage and generation units", IEEE Trans. Power Del., vol. 10, pp. 1249-1254, Jul. 1995.

[4] P. Mahat, Z. Chen, and B. Bak-Jensen, "A hybrid islanding detection technique using average rate of change of voltage change and real power shift", IEEE Trans. Power Delivary, vol. 24, no. 2, pp. 764-771, Apr. 2009

[5] W. Freitas, Z. Huang, and W. Xu, "A practical method for assessing the effectiveness of vector surge relays for distribute generation applications", IEEE Trans. Power Del., vol. 20, pp. 57-63, Jan. 2005

[6] W. Freitas, W. Xu, C. M. Affonso, and Z. Huang, "Comparative analysis between ROCOF and vector surge relays for distributed generation applications", IEEE Trans. Power Del. , vol 20, no. 2, pp.1315-1324, Apr. 2005

[7] S.R. Samantaray, T.M. Pujhari, B.D. Subudhi, A new approach to islanding detection in distributed generations, in: Third IEEE International Conference on Power Systems, IIT, Kharagpur, India, December 27–29, 2009.

[8] G. A. Smith, P. A. Onions, and D. G. Infield, "Predicting islanding operation of grid connected PV inverters," IEE Proc. Electric Power Applications, vol. 147, pp. 1-6, Jan. 2000.

[9] G.Hung, C.Chang,C.Chen; , "Automatic phase-shift method for islanding detection of grid-connected photovoltaic inverters," Energy Conversion, IEEE Transactions on , vol.18, no.1, pp. 169- 173, Mar 2003.

[10] J.Yin; L. Chang C.Diduch.; , "A New Adaptive Logic Phase-Shift Algorithm for Anti-Islanding Protections in Inverter-Based DG Systems," Power Electronics Specialists Conference, PESC '05.IEEE 36th , vol16., pp.2482-2486, June 2005.

[11]S. Yuyama, T. Ichinose, K. Kimoto, T. Itami, T. Ambo, C. Okado, K.Nakajima, S.Hojo, H. Shinohara, S. Ioka, M. Kuniyoshi, "A High-Speed Frequency Shift Method as a Protection for Islanding Phenomena of Utility Interactive PV Systems", Solar Energy Materials and Solar Cells,vol. 35, p. 477-486, 1994,

[12]M. E. Ropp, M. Begovic, and A. Rohatgi, "Analysis and performance assessment of the active frequency drift method of islanding prevention," IEEE Tran. Energy Conversion, vol. 14, no 3, pp. 810-816, Sep. 1999.

[13]V.Menon, M.H.Nehrir, "A Hybrid Islanding Detection Technique Using Voltage Unbalance and Frequency Set Point," Power Systems, IEEE Transactions on , vol.22, no.1, pp.442-448, Feb. 2007.

[14]P.Mahat, Z. Chen,B .Bak-Jensen,.; , "A Hybrid Islanding Detection Technique Using Average Rate of Voltage Change and Real Power Shift," Power Delivery, IEEE Transactions on , vol.24, no.2, pp.764-771, April 2009.

[15]J. Yin, C.P Diduch, L. Chang; , "Islanding Detection Using Proportional Power Spectral Density," Power Delivery, IEEE Transactions on , vol.23, no.2, pp.776-784, April 2008.

[16] A.H. Mohammadzadeh Niaki and S. Afsharnia "A new passive islanding detection method and its performance evaluation for multi-DG systems", vol.110, pp.180-187jan 2014.

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

[18] M. Moradzadeh, M. Rajabzadeh, M. M Bathaee, A. Novel, "Hybrid islanding detection method for distributed generations", Third international conference on electric utility deregulation and restructuring and power technologies,vol.1,no.6,.pp.2290–2295, 2008

[19] G. Walid, C. P. Morsi, C.Diduch, and L. Chang, "A New Islanding Detection Approach Using Wavelet Packet Transform for Wind-Based Distributed Generation", *IEEE Trans. on Power Electronics for Distribution System (PEDG)*, vol.18, no 4 pp. 495-500, Apr 2010.

[20] C.T.Hsieh, J.M. Lin and S.J. Huang, "Enhancement of islanding-detection of distributed generation systems via wavelet transform-based approaches", *International Journal of Electrical Power & Energy Systems*, vol. 30, no. 10, pp. 575-580, Dec. 2008.