2010 IEEE International Conference on Power and Energy (PECon2010), Nov 29 - Dec 1, 2010, Kuala Lumpur, Malaysia

New Islanding Detection Technique for DG Using Discrete Wavelet Transform

Reza Shariatinasab
Faculty of Engineering
Birjand University
Birjand, Iran.
Email: Shariatinasab@ieee.org

Mohsen Akbari
Electrical Engineering Dept.
K. N. Toosi University of Technology
Tehran, Iran.
Email: Mohsenakbari@ee.kntu.ac.ir

***Abstract*—Islanding phenomenon is a problem for Distributed Generator (DG) based networks leading to troubles in voltage and frequency control and other power quality issues. This paper describes the development of a method based on Discrete Wavelet Transform (DWT), in order to detect islanding for DGs. This method detects the islanding state only by evaluating the terminal current of DGs. Hence, different types of current signal in the case of fault occurrence, load and capacitor switching and motor starting have been investigated. In order to increase the accuracy of the wavelet analysis, the proposed algorithm is executed for each type of current signals using different types of mother wavelets, decomposition levels, length of data window and moving size of window to decide on the best assumption of each parameter. The results of the study show that the proposed method can detect the islanding state within a time less than one third of a cycle with a good accuracy.**

***Keywords* — Discrete Wavelet Transform; Distributed Generation; Islanding**

I. INTRODUCTION

During the few past decades, many advances have been made in the field of Distributed Generators (DGs) and there is renewed interest in it. Unlike large power plants, DGs can be installed at or near the loads and its main use is in active power generation [1]. So, reduced environment pollution, reduced need to construct the new transmission lines, increased reliability, increased efficiency of the network and improved power quality are the reasons to use them [2, 3].

An inevitable concomitant of the use of distributed generation is unintentional islanding. The unintentional islanding condition is defined in [4] and occurs when “a portion of the utility system that contains both load and distributed resources remains energized while it is electrically isolated from the remainder of the utility system, due to a fault upstream or any other disturbance” [5, 6]. Failure to trip unintentional islanded DG can lead to a number of problems for these resources and the connected loads, which includes power quality, safety and operation problems [3, 7].

IEEE 929-1988 standard [4] requires the disconnection of DG once it is islanded and IEEE 1547-2003 standard [7] stipulates a maximum delay of 2s for detection of an unintentional island and all DGs ceasing to energize the distribution system. Hence, it is essential to detect islanding both quickly and accurately.

Many techniques have been proposed to detect islanding [3-14]. The important issue for the islanding detection algorithms is the detection time. Islanding detection techniques can broadly be classified into two techniques [8]:

- Remote techniques
- Local techniques

Remote techniques (or telecommunication based techniques) are based on the communication between utilities and DGs. Supervisory Control and Data Acquisition (SCADA) or power line signaling scheme can be used to determine when the distribution system is islanded. These techniques have better reliability but they are expensive to implement especially for small systems. Therefore, local techniques are widely used to detect islanding and are based on data available in the terminal of DGs. They can further be divided into passive and active techniques [5].

Passive techniques make decisions based on the measured electrical quantities such as voltage and frequency, etc. They do not interfere with DG operation. However, the main problem with the passive detection techniques is that, it is difficult to detect islanding when the load and generation in the islanded system closely match. Furthermore, special care has to be taken while setting the thresholds for these parameters. If the threshold is too low, then it could result in nuisance tripping of DG and if the threshold is set too high, islanding may not be detected.

The limitation of the passive detection techniques can be overcome by active techniques, which can detect islanding even under a perfect match of generation and load in the islanded system and have a faster response and a smaller NDZ compared to passive approaches [8]. In active techniques, the specified disturbances are injected into the network in such a way that the response of DG is detected whenever an islanding condition takes place. The problems with these techniques are that the perturbations are injected at predefined intervals even though it is unnecessary during most operating conditions. Also, if islanding occurs during an interval, then it has to wait for next perturbation to be applied before it can be detected, which further elongates the detection time [5].

Wavelet transform based techniques have been previously used for islanding detection in [10-14]. As analyzed from theoretical point of view, wavelet can be formulated via a family of basis functions such that signals can be described in a localized time and frequency format. Moreover, employing long windows at low frequencies and short windows at high frequencies, wavelet transform will be capable of comprehending time and frequency information simultaneously. Therefore, for transients in time-varying signals, they would be supervised more effectively using wavelet, thereby encouraging the application of such method to enhance the detection capabilities [15].

In [10] wavelet transform was used to process the negative sequence voltage and current signals. Then standard deviation of wavelet coefficients and change in energy were found out to detect islanding events from non-islanding ones. Also, standard deviation of the negative sequence impedance is found out for islanding events. In [11] wavelet transform was applied to measured output power of DGs and then the decomposed signal was used to detect islanding. In [12-13] absolute value of certain wavelet coefficient (of voltage or frequency signal) was compared against a threshold value to detect power islands. Also, in [14] wavelet transform is used to analyzing of voltage in grid-connected DGs.

As drawbacks, the aforementioned methods require to measure several electrical quantities or much time is found out which clearly detect islanding.

This paper presents a new algorithm of local-type methods, based on discrete wavelet transform (DWT), with a large detection zone that detects the islanding event on the network in a very short time. The only parameter used in this method is the terminal current of DGs. The result of studies shows that the proposed technique, in contrast with the current active and passive methods, can correctly detect the islanding event within a time less than one third of a cycle, i.e. less than 5.5 ms for frequency 60 Hz. Also, it is suitable for the networks with a large number of DGs.

II. DESCRETE WAVELET TRANSFORM (DWT)

DWT overcomes many of problems associated with Fourier analysis such as fixed resolution, and the evaluation of frequencies within a specific time window [16]. In DWT, the mother wavelet is shifted and scaled by choosing the scale and shift parameters $a=a_0^m$ and $b=nb_0a_0^m$ respectively, where a_0 and b_0 are constant values. With $a_0>1$, $b_0>1$ and $m, n \in Z$, where Z is positive integer, DWT can be written as:

$$DWT(m,n) = \frac{1}{\sqrt{a_0^m}} \sum_{k=-\infty}^{+\infty} X(k)\psi\left(k - \frac{nb_0 a_0^m}{a_0^m}\right) \quad (1)$$

Where Ψ and $X(k)$ are respectively discrete wavelet and measured signal functions. The value of a_0 and b_0 should be selected in a way that mother wavelets constitute an orthogonal basis. For instance, this condition is made for a_0=2, b_0=1.

The ability to provide variable time-frequency resolution is hallmarks of wavelet transform. This transform is useful for investigation of transient states, power quality assessment and modeling in power system [15-17].

Wavelet transform is a well-suited tool for analyzing high-frequency transients in the presence of low-frequency components such as non-stationary and non-periodic wide-band signals. Wavelet analysis mainly employs the expansion and contraction of basis function to detect simultaneously the characteristics of global and local of measured signal. The basis function is also called the mother (original) wavelet [17].

By (1), main signal is separated into two parts: approximation part (a_1, a_2, a_3, …) and detail part (d_1, d_2, d_3, …). The approximation part is the main part of the signal and includes low-frequency components while the detail part includes transient and high-frequency components. This trend of detail and approximation continues to each level of analysis [16-18]. Fig. 1 shows decomposition of main signal to different frequency levels in the analysis progress.

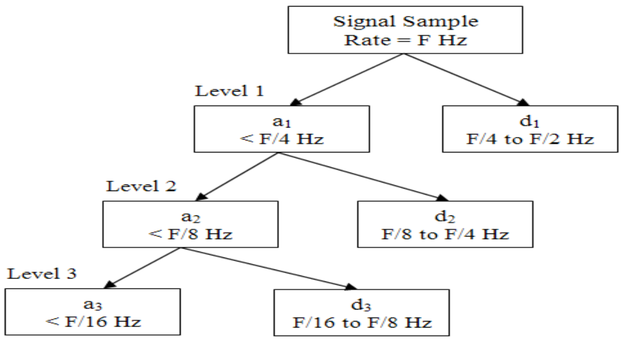

Figure 1. Decomposition in Discrete Wavelet Transform, DWT

Frequency limitation of each decomposition level in DWT depends on sampling frequency of the main signal. Table I, shows the frequency characteristics of decomposition levels for sampling frequency of 10 kHz.

TABLE I.
FREQUENCY CHARACTERISTICS OF DIFFERENT DECOMPOSITION LEVELS IN DWT

Level Label	Frequency (Hz)
d_1	5000-10000
d_2	2500-5000
d_3	1250-2500
a_3	0-1250

However, considering a signal consisting of 2^M data points, where M is an integer, DWT requires 2^M wavelet coefficients to fully describe the signal. DWT decomposes the signal into $M+1$ levels, where the level is denoted as j and the levels are numbered: $i= -1, 0, 1, 2, 3\ldots, M-1$ [15].

Under any transient disturbance, there are some high frequencies components on current waveform that is not detected on a power frequency by conventional methods. Furthermore, during any transient phenomenon, e.g. occurred islanding condition, the amplitude of current waveform is changing quickly. High frequency components been on the current waveform, could not be discerned at power frequency while must be discerned by a high frequency analysis. In the proposed method, current is only parameter should be measured to detect the islanding event.

To detect the islanding state, some types of wavelet family such as daubechies, coiflet, meyer and symlet were analyzed. Considering the obtained results, a 'Haar' mother wavelet is selected as it requires the least decomposition levels and consequently the least detection time to suitably detect the islanding.

The 'Haar' wavelet identifies key features such as periodic time variance and the relationship with filter bank analysis. It is the simplest wavelet imaginable and certainly the earliest. The 'Haar' wavelet is discontinuous, and resembles a step function as below [16]:

$$\psi_{Haar}(t)=\begin{cases} 1 & 0\le t<1/2 \\ -1 & 1/2\le t<1 \\ 0 & otherwise \end{cases} \tag{2}$$

III. PROPOSED ALGORITHM

The proposed algorithm is based on the study of disturbances existed in the terminal current waveform of DGs. Note, once the islanding event is occurred, the transient component continues for a few cycles after the switching operation and there will be high frequency disturbances on the current waveform of DGs caused by the switching operation.

In this method, after studies done by the authors for different phenomena, the current and the third level of detail (d_3) are used to detect the islanding condition. In the first step, the ratio of maximum current magnitude of k^{th} window to the previous window is calculated as follows:

$$Ratio-I_t(k)=\frac{maxI_t(k)}{maxI_t(k\text{-}1)} \tag{3}$$

Where, the limitation is:

$$0.98\le Ratio-I_t(k)\le 1.02 \tag{4}$$

If the calculated ratio satisfies (4) then there is no problem and this means that islanding has not been occurred. For values out of rang of (4), the following criteria could be used to check whether the islanding event takes place or not:

$$Ratio-D_3(k)=\frac{maxD_3(k)}{maxD_3(k\text{-}2)} \tag{5}$$

Considering different studies done, threshold value chosen for (5) is 0.02. This condition can be expressed by:

$$Ratio-D_3(k)\le 0.02 \tag{6}$$

If (5) is less than 0.02, then the islanding event is occurred and trip command should be issued for DGs. Fig. 2 shows the block diagram of the proposed algorithm.

Another important parameter in the proposed algorithm is moving size of the data window. Note, decreasing the moving size, reduces total time of detection. So, the moving size should be decreased as possible.

Each level i consists of $j = 2^i$ wavelet translated and equally spaced $2^M/j$ intervals apart; Thereby, increasing the decomposition levels also increases detection time. Hence, decomposition levels should be selected as less as possible. Considering studies done, it was found out that third decomposition level with 20 samples as length of the data window and 17 samples as the moving size of the data window is accurate leading to detect the islanding state within maximum 52 samples i.e. 5.2 ms.

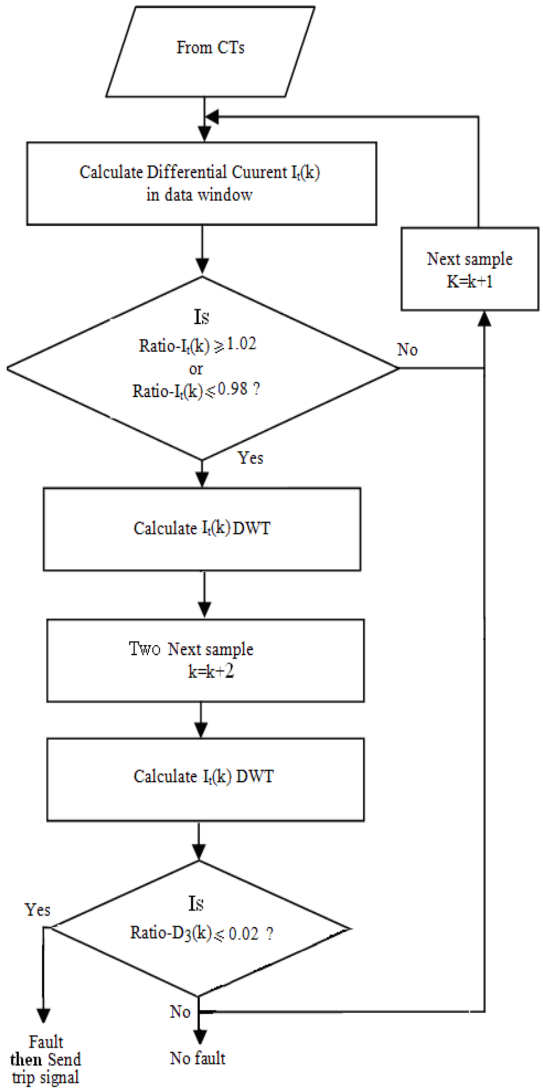

Figure 2. Schematic diagram of the proposed algorithm

IV. CASE STUDY

The case study in this paper consists of two Synchronous DGs (DG1 and DG2) operating on PQ mode, and is a part of Iranian distribution network located in Tehran (Fig. 3). Tables II-IV present the network data. At first, the network was simulated by ETAP Software. After gathering the required data, DWT analysis was done using MATLAB toolbox.

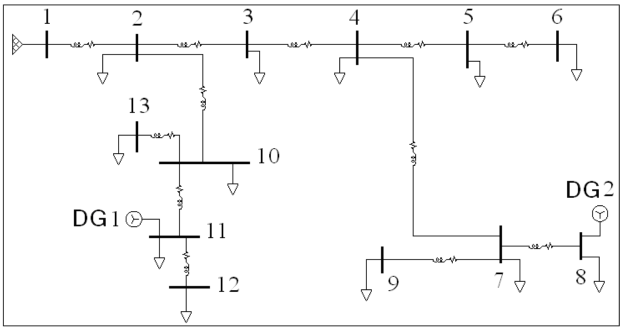

Figure 3. Case study

TABLE II.
DATA OF DGS

DG Number	P (MW)	Q (MVAR)
1	3	1.25
2	1.277	0.83

TABLE III.
LINE DATA

Line	R (ohm)	X (ohm)
1-2	0.176	0.138
2-3	0.176	0.138
3-4	0.045	0.035
4-5	0.089	0.069
5-6	0.045	0.035
4-7	0.073	0.073
7-8	0.074	0.058
7-9	0.093	0.093
2-10	0.116	0.091
10-11	0.063	0.05
11-12	0.068	0.053
10-13	0.062	0.053

TABLE IV.
LOAD DATA

Bus Number	Load	
	P (kW)	Q (kVAR)
1	0	0
2	1.483	0.78
3	1.047	0.783
4	1.853	1.273
5	1.06	0.63
6	0.79	0.573
7	1.533	0.487
8	1.277	0.83
9	1.103	0.8
10	2.237	1.797
11	1.15	0.31
12	2.153	0.923
13	1.873	0.8

V. SIMULATION RESULTS

In order to achieve an accurate detection algorithm, all the cases which affect on the terminal current of DGs are analyzed. Figs. 4 and 5, show current waveform and related three decomposition levels using 'Haar' mother wavelet for DG1 and DG2 respectively, due to opening the breaker on line 7-8. The result of Fig. 4 for DG1 shows that there is no problem since the ratio of the changed current in related data window satisfies (4). In order to get a conservative result, it was assumed that the generated power of DG2 is equal to the customer load at the connected bus. Therefore, once the line 7-8 is disconnected, the difference between the generated and consumed power in bus 8 will be zero, while the ratio of the changed current in related data window for DG2 is less than 0.98 i.e. does not satisfy (4). In the next step, the proposed algorithm after checking (6) detects islanding event and issues trip command for DG2.

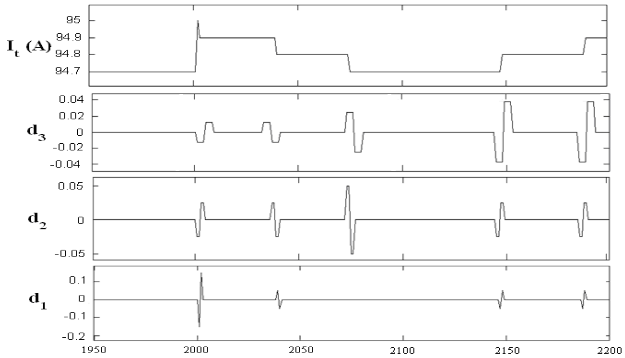

Figure 4. The waveform of terminal current of DG1, due to opening the breaker on line 7-8, d_1-d_3 are detail components of main signal

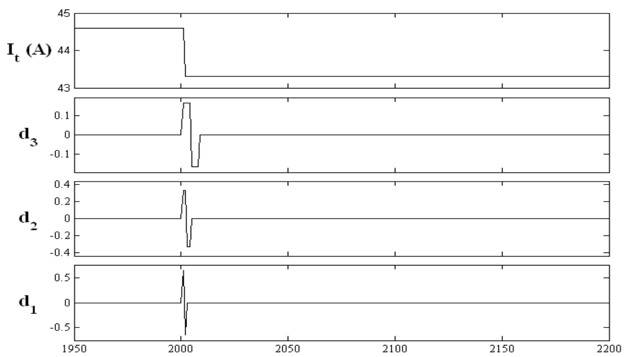

Figure 5. The waveform of terminal current of DG2, due to opening the breaker on line 7-8, d_1-d_3 are detail components of main signal

Furthermore, Figs. 6-15, show the current waveform of DGs due to opening the breaker on lines 1-2, 2-3 and 2-10, motor starting at bus 3 and capacitor switching at bus 12.

From Fig. 6, ratio of the changed current in related data window for DG1 is less than 0.98 and in the next step the value obtained by (5) is less than 0.02. Thus in this condition, islanding would be detected. Moreover, for DG2 the value of (3) is more than 1.02 and the value of (5) is less than 0.02. So, islanding for both units would be correctly detected, too.

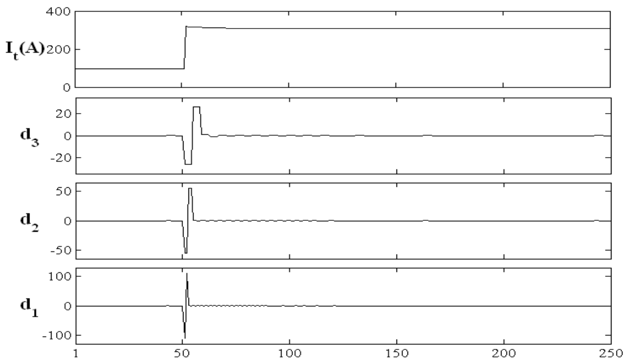

Figure 6. The waveform of terminal current of DG1, due to opening the breaker on line 1-2, d_1-d_3 are detail components of main signal

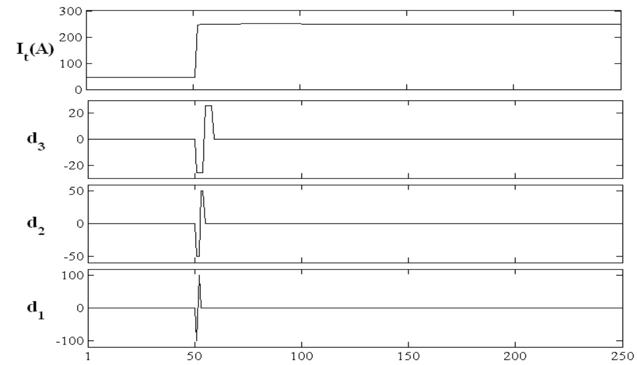

Figure 7. The waveform of terminal current of DG2, due to opening the breaker on line 1-2, d_1-d_3 are detail components of main signal

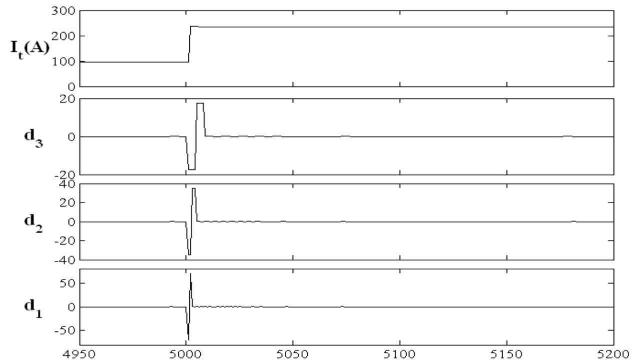

Figure 10. The waveform of terminal current of DG1, due to opening the breaker on line 2-10, d_1-d_3 are detail components of main signal

Also, From Figs. 8 and 9, for DG1 the value of (3) is less than 0.98 and the value of (5) is more than 0.02. But for DG2 the values of (3) and (5) are less than 0.98 and 0.02, respectively. So, islanding for DG2 would be detected while could not be correctly detected for DG1.

From Fig. 10, for DG1 the values of (3) and (5) are less than 0.98 and 0.02, respectively. But for DG2 in Fig. 11 the value (3) is less than 0.98 and the value (5) is more than 0.02. So again, the islanding would be correctly detected for DG1 while could not be correctly detected for DG2.

Beside, from Figs. 12-15 for both motor starting and capacitor switching operations the value of (3) is less than 0.98 and the value of (5) is more than 0.02. Hence, in both operations, islanding would not be correctly detected for DGs.

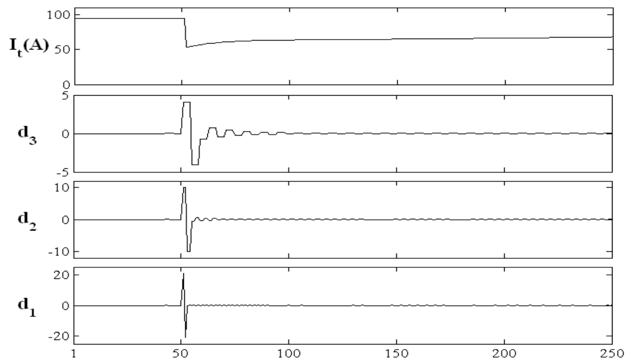

Figure 8. The waveform of terminal current of DG1, due to opening the breaker on line 2-3, d_1-d_3 are detail components of main signal

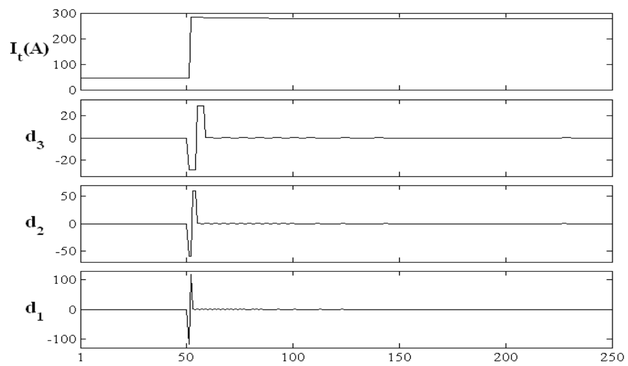

Figure 9. The waveform of terminal current of DG2, due to opening the breaker on line 2-3, d_1-d_3 are detail components of main signal

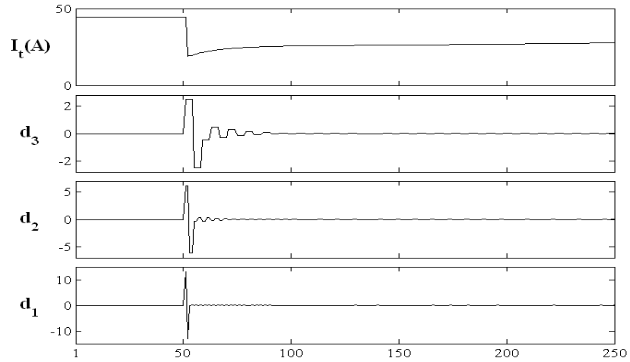

Figure 11. The waveform of terminal current of DG2, due to opening the breaker on line 2-10, d_1-d_3 are detail components of main signal

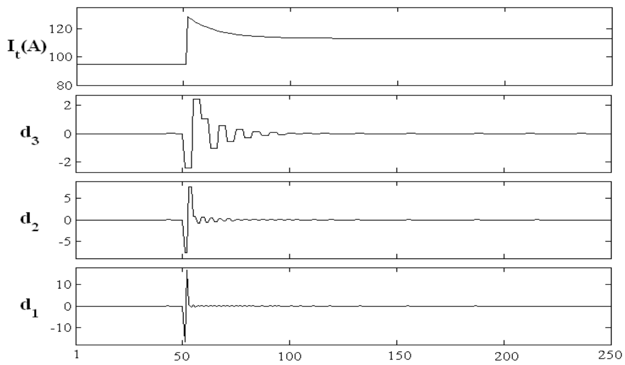

Figure 12. The waveform of terminal current of DG1, due to motor starting at bus 3, d_1-d_3 are detail components of main signal

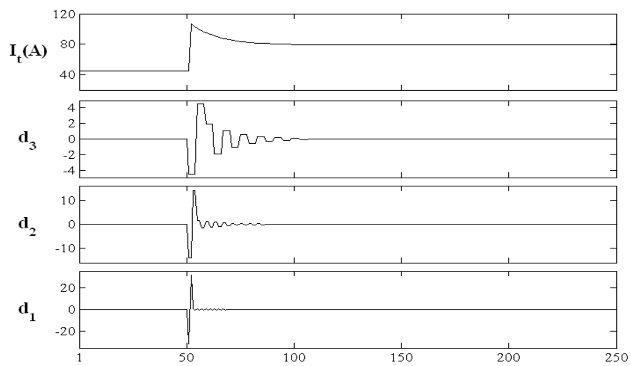

Figure 13. The waveform of terminal current of DG2, due to motor starting at bus 3, d_1-d_3 are detail components of main signal

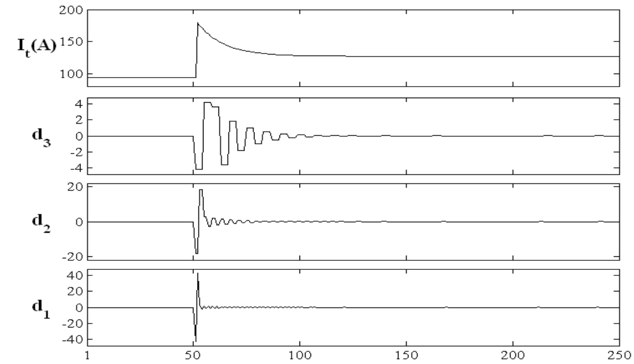

Figure 14. The waveform of terminal current of DG1, due to capacitor switching at bus 12, d_1-d_3 are detail components of main

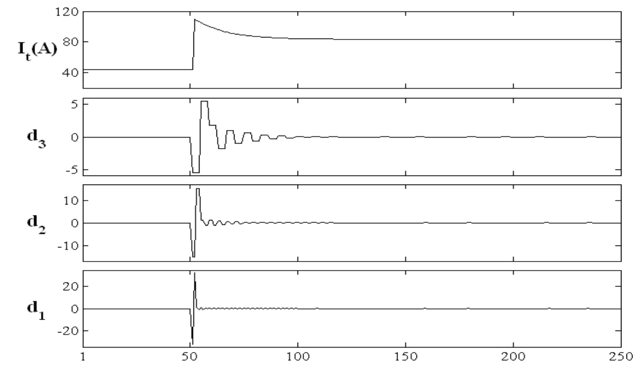

Figure 15. The waveform of terminal current of DG2, due to capacitor switching at bus 12, d_1-d_3 are detail components of main signal

VI. CONCLUSION

In this paper a development of DWT based algorithm is described in order to detect the islanding event for DGs. The proposed algorithm is belonged to local methods. The main advantage of this technique is that the only parameter should be measured is the current waveform of DGs.

The studies done by the authors proved that the 'Haar' mother wavelet and third decomposition level with 20 samples as the length of the data window and 17 samples in moving window is the best choice to do the proposed DWT based algorithm.

Also, the proposed method can detect the islanding event within a time less than one third of a cycle, i.e. 5.5 ms for grid frequency of 60 Hz. Furthermore, the technique suggested in the paper covers defects of the current active and passive methods. In short, it can detect islanding with a good accuracy and also it is suitable for the networks with a large number of DGs, even when the load and generation in the islanded system closely match.

REFERENCES

[1] P. Chiradeja, "Benefit of distributed generation: A line loss reduction analysis," *IEEE/PES Transmission and Distribution Conf. and Exhibition, china*, pp. 1-5, 2005.

[2] A. M. Borbely, and J. F. Kreider "Distributed generation: The power paradigm for the new millennium", CRC Press, 2001.

[3] J. Yin, L. Chang, C. Diduch, "Recent developments in the islanding detection for distributed power generation," *IEEE Large Engineering Systems Conf. on Power Engineering*, pp. 124-128, Jul. 2004.

[4] *IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems*, IEEE Std. 929, 2000.

[5] P. Mahat, Z. Chen, and B. B. Jensen, "A hybrid islanding detection technique using average rate of voltage change and real power shift," *IEEE PWRD.*, vol. 24, No. 2, pp. 764-771, Apr. 2009.

[6] V. Menon, and M. H. Nehrir, "A hybrid islanding detection technique using voltage unbalance and frequency set point," *IEEE Trans. Power Systems*, vol. 22, No. 1, pp. 442-448, Feb. 2007.

[7] *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*, IEEE Std. 1547, 2003.

[8] T. Skocil, O. G. Bellmunt, D. M. Miracle, S. G. Arellano, J. R. Duran, "Passive and active methods of islanding for PV systems," *European Conf. on Power Electronics and Applications*, pp. 1–10, Sep. 2009.

[9] M. E. Ropp, and et al., "Determining the relative effectiveness of islanding detection methods using phase criteria and nondetection zones," *IEEE Trans. on Energy Conversion*, vol. 15, No. 3, pp.290-296, Sep. 2000.

[10] S. R. Samantaray, T. M. Pujhari, and B. D. Subudhi, "A new approach to islanding detection in distributed generations," *International Conf. on Power Systems*, pp. 1-6, Dec. 2009.

[11] A. Pigazo, M. Liserre, R. A. Mastromauro, V. M. Moreno, and A. D. Aquila, "Wavelet-based islanding detection in grid-connected PV systems," *IEEE Trans. on Industrial Electronics*, vol. 56, No. 11, Nov. 2009.

[12] 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.

[13] Y. H. Liu, T. S. Luor, S. J. Huang, J. M. Lin, "Method and system for detecting stand-alone operation of a distributed generating system," US Patent 7342758, Mar. 2008.

[14] Y. Zhu, Q. Yang, J. Wu, D. Zheng, Y. Tian, "A novel islanding detection method of distributed generator based on wavelet transform," *International Conf. on Electrical Machines and Systems*, pp. 2686 – 2688, Oct. 2008.

[15] B. Jha, and K. R. M. Rao, "Doubly fed induction generator analysis through wavelet technique," *Journal of Engineering Science and Technology Review*, pp. 63-67, 2009.

[16] I. S. Cade, P. S. Keogh, and M. N. Sahinkay, "Fault identification in rotor/magnetic bearing systems using discrete time wavelet coefficients," *IEEE/ASME Trans. on Mechatronics*, vol. 10, No. 6, pp. 648-657, Dec. 2005.

[17] Z. L. Gaing, and H. S. Huang, "Wavelet-based neural network for power disturbance classification," *IEEE, Power Engineering Society General Meeting,* vol. 3, Jul. 2003.