

Wavelet Entropy: Application in Islanding Detection

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Abstract:-With the increased demand of electrical power, penetration of distributed generation in the grid is also increased. Connecting distributed generators with grid created many interconnection problems. Islanding detection is an important and challenging issue of them. Several methods are available in literature based on passive and active detection schemes. Both schemes have their own problems like non detection zone, nuisance tripping, and power quality degradation. This paper proposes wavelet entropy based passive detection scheme. This method can detect islanding with zero non detection zone (NDZ) and without affecting the output power quality. The implementation of the method is done on Matlab- Simulink and its effectiveness is test for standard IEEE test circuit.

Keywords— **Distributed generators, Islanding detection, Wavelet, Energy Entropy, Non detection zone, Inverter.**

1 Introduction

Islanding is a situation when a DG is disconnected from the main utility but remains energized and continues to supply local loads. This condition can result in many potential hazards since supply is without control and / or supervision of utility. Therefore this condition is needs to be detected and protected. The basic protection schemes includes over current, over- and under voltage and over- and under frequency schemes. In literatures many other indicators such as rate of change of frequency, power, and phase jump are used to detect islanding [1-3]. Islanding is detected by observing and analysing the change in these indicators. Such schemes are known as passive schemes. The purpose of these schemes is to detect abnormal conditions and to provide signal to switch off the DG. The detectable changes in above parameters occur when there is a large mismatch in the power generated by the DG and power required by the load. When the power mismatch is very less, the above schemes are fail to detect the islanding scenario. This range of power mismatch is known as non delectation zone of the schemes. It has been

found that effectiveness of passive schemes depends on threshold setting of the parameters and range of their non detection zone. If the threshold range is set small, nuisance tripping could occur. Hence passive methods are not sufficient for anti islanding protection [4].

To eliminate non detection zone of passive methods, active methods are included in protection. These schemes introduce perturbation to the parameters of the system such as voltage, frequency or impedance. When the DG is grid connected these disturbance signals do not affect the performance of the system. When the DG is islanded disturbance signal drift the parameter to detectable limits. But this external disturbance degraded the output power quality [5].

In response to above mentioned detection problems a new technique is proposed to build an anti islanding scheme. The main advantage of the proposed scheme is to reduce the non detection zone of passive method to zero and do not provide any degradation in power quality. The new method is based on voltage measurement at the point of common coupling and analyses its wavelet energy entropy for every two cycle moving window. The new method reduces the

NDZ without causing any perturbation in the system.

2 Power mismatch or Non- detection zone

A NDZ is defined as a load or range of loads for which an islanding detection method fails [6]. An IEEE standard test circuit used for islanding detection can explain the Non delectation zone. To comply with the IEEE 1547:2003 standards, the definition of RLC load under lest condition is

- The RLC load must resonate at the nominal frequency of the grid.
- The Power factor of the RLC load is set to 2.5.
- The power generated by the DG should match that of the RLC load.

The relation between the power mismatch and the voltage / frequency thresholds for the voltage and frequency protection methods can be expressed as

$$\left[\frac{V_{nom}}{V_{max}}\right]^2 - 1 \leq \frac{\Delta P}{P} \leq \left[\frac{V_{nom}}{V_{min}}\right]^2 - 1 \quad [1]$$

$$Q_f \left[1 - \left(\frac{f_{nom}}{f_{min}}\right)^2\right] \leq \frac{\Delta Q}{P} \leq Q_f \left[1 - \left(\frac{f_{nom}}{f_{max}}\right)^2\right] \quad [2]$$

The max and min values of voltage and frequency protection are selected as with the levels specified in various standards. Graphical representation of non detection zone is shown in the Figure 1.

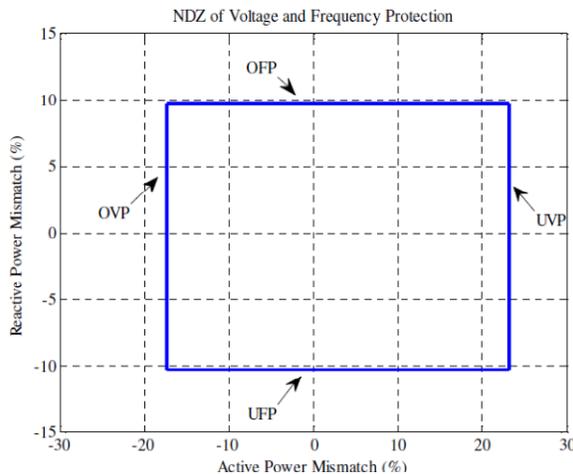


Fig. 1 NDZ of over/under voltage and frequency protection

3 Wavelet Transform and Filter Banks

The Wavelet Transform is a power time frequency method to analyse a signal within different frequency ranges by means of dilating and transiting of a single function named mother wavelet [7]. The DWT is implemented by mallet’s algorithm. Mallat algorithm used low pass $h(k)$ and high pass $g(k)$ filter and the frequency band of input signal is divided into high and low frequency components [8]. This process is repeated applying the down sampled low pass filter output into another identical filter pair. This decomposes the signal into approximation $c(k)$ and detail $d(k)$ coefficient for various scales of resolutions. The DWT of the signal is computed through frequency of filter bank. In each level low pass filter decomposes the input signal of that stage and provides new approximation and detailed coefficients. The process is depicted in Figure2.

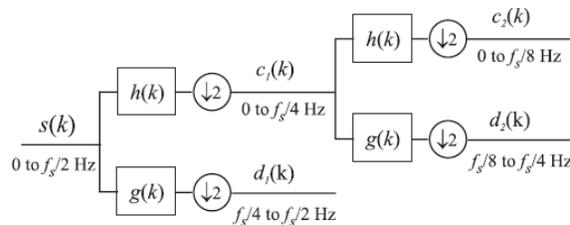


Fig. 2 Wavelet Decomposition

Wavelet technique has been used in several power system applications e.g. detection, feature extraction, de-noising and data compression of power quality waveforms, power system protection etc [9].

In the proposed work various power system disturbances are simulated for different levels and the best identification has been found out through calculation of energy entropy. Finally entropy is used for indication of islanding. The coefficients of the filter pairs are depend on the selected mother wavelets. Various mother wavelets are used for this purpose in which daubechies 4

wavelet was most suitable, due to its good time resolutions. It provides a clear indication of islanding.

3.1 Energy Entropy

The wavelet entropy appears as a measure of the degree of order/ disorder of the signal, so it can provide useful information about the underlying dynamical process associated with the signal. A very ordered process can be a signal with a narrow band spectrum. A wavelet representation of such a signal will be resolved in one unique wavelet resolution level. All wavelet energies will be almost zero except for the wavelet resolution level that includes the representing signal frequency. A signal generated by a random process will represent a disordered behaviour. This signal will have significant contribution from all frequency bands. Consequently wavelet coefficient energy will be equal for all resolution levels and WE will take their maximum value.

The paper used normalized Shannon energy entropy. The definition of non normalized Shannon entropy is as follows [10]

The wavelet energy spectrum at scale j and instant k is:

$$E_{jk} = |D_{jk}|^2 \quad [3]$$

The nonnormalized Shannon entropy at scale j , in a moving data window goes through the detail coefficients shifting 128 samples at a time, is

$$E_j = -\sum_{k=1}^{N_w} E_{jk} \log E_{jk} \quad [4]$$

N_w is the window length (number of samples contained in one moving window the fundamental frequency of the original signal).

3.2 Application of Energy Entropy

Wavelet entropy measure based on wavelet analysis is able to observe the unsteady signals and complexity of the system at time-frequency plane. To identify the transient signal, wavelet entropy measures is a feature, which have some unique capabilities. In power system many signals are composed of different frequency components such as fault transient signals on

transmission line, other disturbances like oscillatory transient, switching of non linear loads breaking signals etc. Based on this, some of the power system disturbances are simulated and their change in entropy has shown here [11]. To simulate the disturbances non-normalized Shannon entropy is used. The mother wavelet is taken as deubachies 4 due to its simplicity and having good time localisation. The sample frequency is 20kHz. The disturbance signal is decomposed into fifth levels. For computation results of each scenario and their figures contain the following plots:

- The disturbance signal;
- The detailed signal at WT level 1(d1);
- The detailed signal at WT level 2(d2);
- The detailed signal at WT level 3(d3);
- The detailed signal at WT level 4(d4);
- The detailed signal at WT level 5(d5);
- The non normalized Shannon Entropy Result;

Voltage sags and swells

A typical definition is given as “A measured voltage having a value greater than or less than the nominal voltage for a period greater than 1 min when used to describe a specific type of long duration variation.” Typical values are 1.1 to 1.2 p.u. for over voltage and 0.8 to 0.9 p.u. for under voltage. [12]

The voltage sag may be caused by a fault current, switching of heavy loads or starting of large motors. Voltage sag with a 30% drop or more is considered severe.

Simulation expression for voltage sag is,

$$S = p(t) * \sin(2 * \pi * 50 * t), \quad [5]$$

$$\text{With } p(t) = \begin{cases} 1 & t \in [0, 0.06s] \cup [0.16s, 0.2s] \\ 0.5 & t \in [0.06s, 0.16s] \end{cases}$$

Fig. 3 shows a 50% sag disturbance lasting for 5 cycles (occurring from 60ms to 160ms). In the fig. the horizontal axis is marked for the index of sample time, while the vertical axis is for the voltage magnitude. Changes in wavelet transform at different decomposition levels are shown. Two peaks can be observed

from d1 and d2 component, which include one for the start and the other for the end signature. The larger drastic variations indicate that the event has occurred as between the 60ms and 160ms. In rest of the scales d3,d4 and d5 it is difficult to detect the starting or ending point of the voltage sag. The last fig shows the change in entropy value which is very high in comparison to wavelet coefficients.

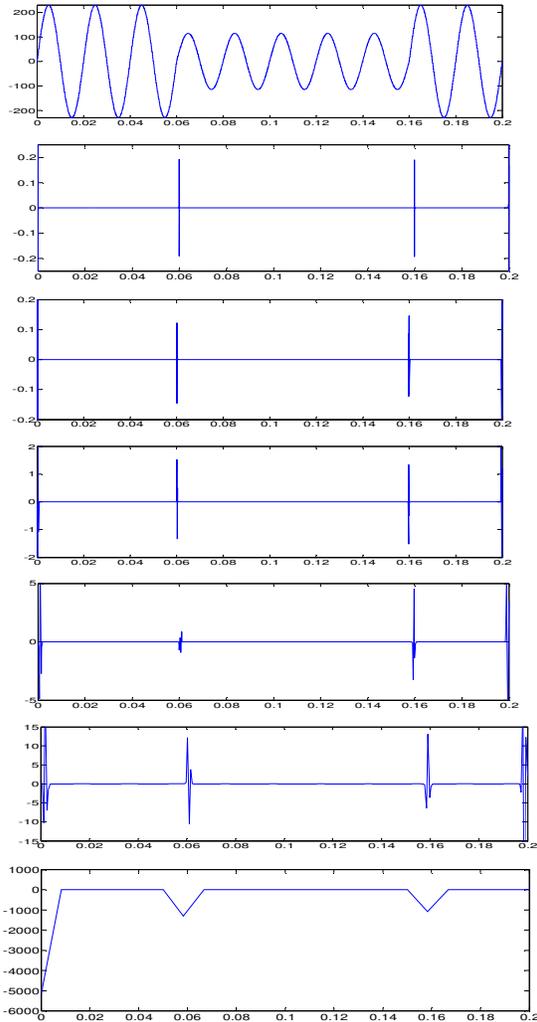


Fig.3 voltage sag, d₁, d₂, d₃, d₄, d₅ and entropy of the signal

In contrast to the voltage sag, voltage swells are a small increase of the rated system voltage. The swell can be seen often on the no faulted phases of a three phase circuit where a single phase short circuit occurs. In delicate

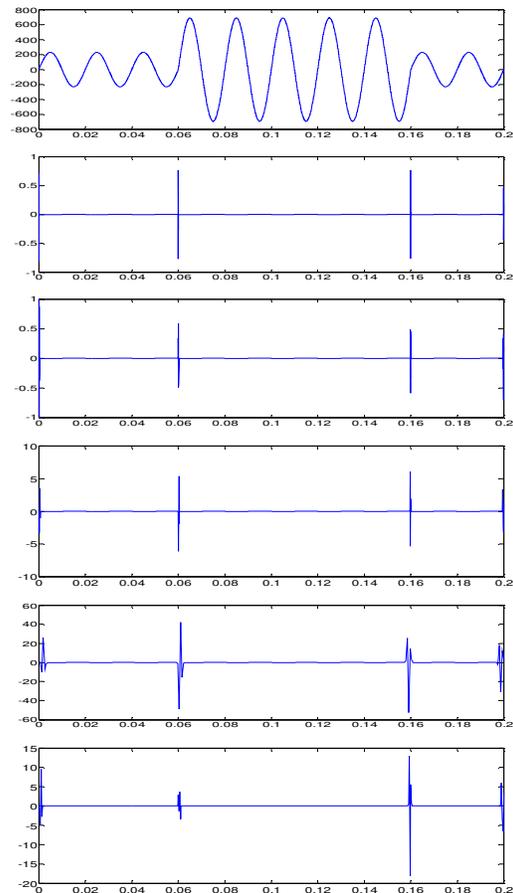
equipment components a swell may cause a premature failure.

Simulation expression for voltage sag is,

$$S = p(t) * \sin(2 * \pi * 50 * t), \quad [6]$$

$$\text{With } p(t) = \begin{cases} 230 & t \in [0, 0.06s] \cup [0.16s, 0.2s] \\ 230 * 3 & t \in [0.06s, 0.16s] \end{cases}$$

Fig. 4 shows a 50% sag disturbance lasting for 5 cycles (occurring from 60ms to 160ms). This fig also shows the similar behaviour as sag. Two peaks can be observed from d1 and d2 component that include one for the start and the other for the end signature. The larger drastic variations indicate that the event has occurred as between the 60ms and 160ms. In rest of the scales d3, d4 and d5 it is difficult to detect the starting or ending point of the voltage swell.



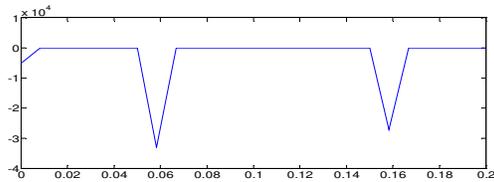


Fig.4 voltage swell, d_1, d_2, d_3, d_4, d_5 and entropy of the signal

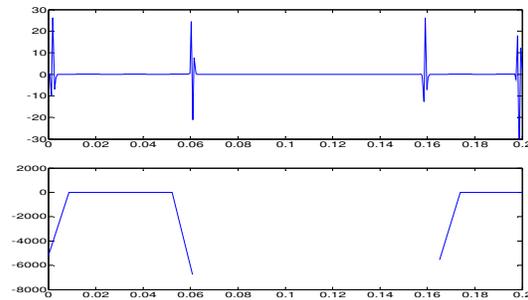


Fig.5 voltage interruption, d_1, d_2, d_3, d_4, d_5 and entropy of the signal

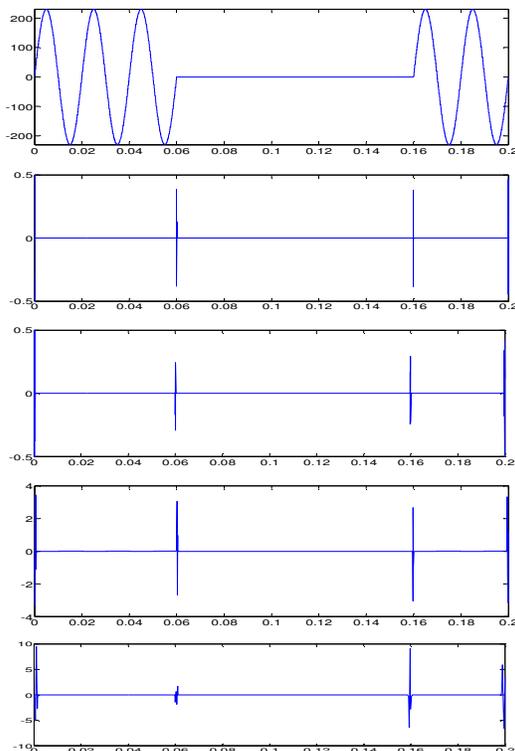
Voltage Momentary Interruption

A momentary interruption [13] is short-time loss of voltage on a power system. Such a disturbance describes a drop of 90~100 percent of the rated system voltage lasting for 0.5 cycle to 1 min. The simulation expression is,

$$S = p(t) * \sin(2 * \pi * 50 * t), \quad [7]$$

$$\text{With } p(t) = \begin{cases} 230 & t \in [0, 0.06s] \cup [0.16s, 0.2s] \\ 0 & t \in [0.06s, 0.16s] \end{cases}$$

In this case power is interrupted for about 100ms. Result of wavelet transform is shown in Fig.5



In all above cases, two peaks are observed, one for start and other for end of the disturbance. As the scale of decomposition increases the magnitude of peaks also increases. The wavelet entropy result has a large magnitude change.

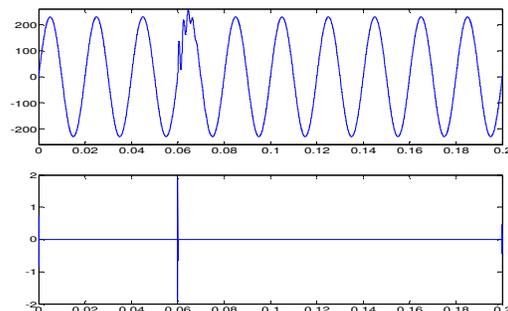
Oscillatory Transients

The next case considered is oscillatory transient. These oscillatory characteristics show the transients result from the capacitor switching. When utility capacitor banks are switched into service early in anticipation of a higher load demand, such transient can be experienced. The simulation expression used to demonstrate this event is,

$$S = p(t) + 230 * \sin(2 * \pi * 50 * t), \quad [8]$$

$$\text{With } p(t) = (1/2) e^{-300(t-0.06)} 230 * \sin(1000 * \pi * (t - 0.06)), t \ge 0.06s$$

In the above voltage waveform the oscillatory transient disturbance occurs at 60ms and lasts about 1/4 cycles.



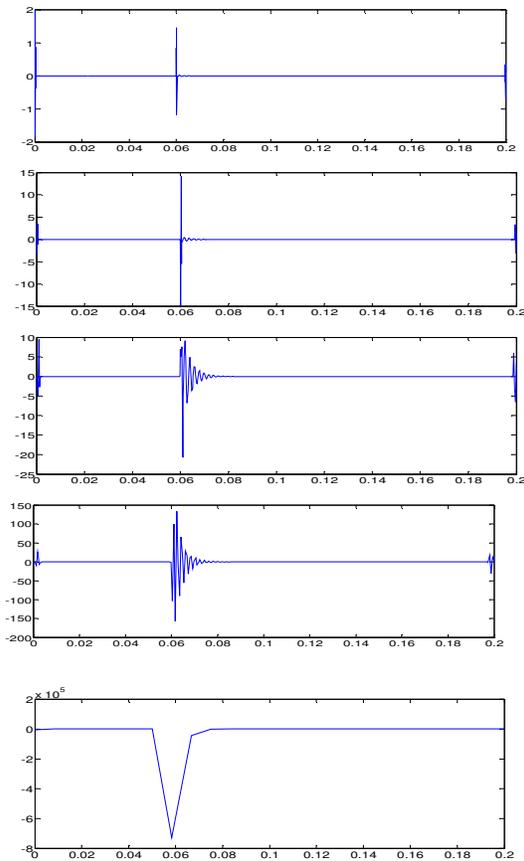


Fig.6 voltage sag, d₁, d₂, d₃, d₄, d₅ and entropy of the signal

Application of the wavelet transform to detect disturbances is an effective technique as starting and ending signal has remarkable change to point out the disturbance but it is difficult to detect the type of disturbance from the wavelet coefficients. If we check the variation in energy entropy of the signal it has a large difference in magnitudes of entropy at each type of disturbance. Table 1 shows the absolute values of the detailed coefficients at each scale of the wavelet decomposition and energy entropy at fifth level of decomposition.

Disturbances	d1		d2		d3		d4		d5		Entropy	
	Starting Pt	End Pt	Starting Pt	End Pt	Starting Pt	End Pt	Starting Pt	End Pt	Starting Pt	End Pt	Starting Pt	End Pt
Voltage Sag	0.2053	0.2053	0.1536	0.1536	1.531	1.531	0.9215	4.539	12.23	13.12	1315	1090
Voltage Swell	0.7707	0.7707	0.5867	0.5867	6.124	6.124	3.686	18.16	48.83	52.47	33100	27200
Momentary Interruption	0.3853	0.3853	0.2934	0.2934	3.062	3.062	1.843	9.08	24.5	26.25	6750	-5540
Oscillatory Transient	1.917	.....	1.459	.....	15	.....	20.69	.....	157.7	.....	7.30E+05	.....

Table 1 Comparison of magnitudes of DWT coeff. and entropy for different types of disturbances

It is very clear that at higher level the magnitude of the indication becomes strong, but identification of the type of disturbance is not possible by these values where as energy entropy has significant difference in magnitude to classify the type of fault. The abundant real-time disturbance data gathered in power systems contain the complexity and uncertainty of the system. It is therefore

significant to mine one or several universal applicable quantities from these data to detect system fault and stability. Hence wavelet analysis combined with entropy theory is used to resolve the problem of identification and is feasible to apply in real time dynamic systems. The islanding in non detection zone is a disturbance of very less amplitude; energy entropy measure could be a significant indicator for that.

4 Proposed Algorithm for Islanding Detection

To resolve the problem of NDZ wavelet entropy is proposed as islanding indicator. The basic idea is to analyse the change in wavelet entropy during islanding. In the proposed method the PCC voltage signal is decomposed up to a chosen level J using DWT signal decomposition and its wavelet entropy is calculated for fixed sample moving window. In this approach islanding is created with 100% matched load and it is found that PCC voltage change is not sufficient to reach the threshold limit of UVP/OVP detector. The DWT coefficients show large changes after islanding. But these changes can occur due to common power system disturbances and harmonics variations (due to variation in non linear load etc). Hence the wavelet entropy at seventh decomposition level calculated once in every two cycle is proposed. Islanding is detected when this calculated entropy becomes greater than a set threshold value.

5 Simulation and Result

To verify the performance of the proposed wavelet entropy based islanding detection method a grid connected inverter is used. The system is simulated on Matlab/ Simulink platform as shown in appendix. The inverter is connected to a DC supply. Dc supply represents DG with storage battery. Islanding is created with zero power mismatch (ie zero NDZ) where load power is exactly equal to the inverter power. The power frequency is 50Hz

and PCC voltage measurement is analysed through wavelet islanding detection block. The simulation is performed at various decomposition level and various mother wavelets. Daubechies 4, (db4) and seventh level decomposition has been found most significant for this purpose. The fig 4 shows the wavelet entropy for different mother wavelets. The islanding scenario is created by using circuit breaker. Comparison of performance of various mother wavelets in islanding and nonislanding conditions is shown in fig 4. daubechies (db4,db6,db20) shows remarkable change on entropy in islanding and non islanding condition. Harr, db2, and bior3.9 show undefined conditions. db4 is selected for this simulation for its compactness, and localization properties. For this case study islanding is created at 0.4 seconds. Discrete time simulation with sampling time 50 microsec is used. Three phase voltage and current at point of common coupling is captured. From this voltage of phase A is taken for analysis. It can be seen from Figs. 5(a)-(b) that after islanding (at 0.4s) the PCC voltage and frequency remains within the operating range of OFP/OVP relays. Thus, confirming that the passive methods based on the OVP/UVP and OFP/UFV relays fail to detect islanding under such conditions. The proposed wavelet method shows the DWT coefficients (absolute value) and corresponding energy entropy calculated as per equation [4]. It is clear from the figure that change in entropy value is very large as compared to DWT coefficients. Therefore it is a clear indication of islanding condition. The time taken by this method is 2 to 3 cycles, which is well within the acceptable limit.

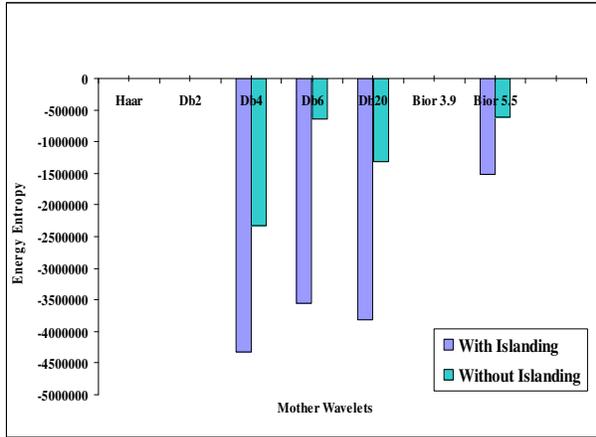


Fig. 4 Comparison of energy entropy for various mother wavelets.

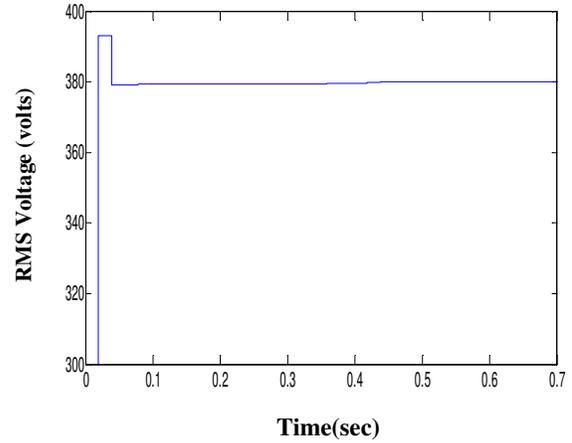


Fig. 5(c) RMS Voltage at point of common coupling (volt) on islanding at 0.4 sec

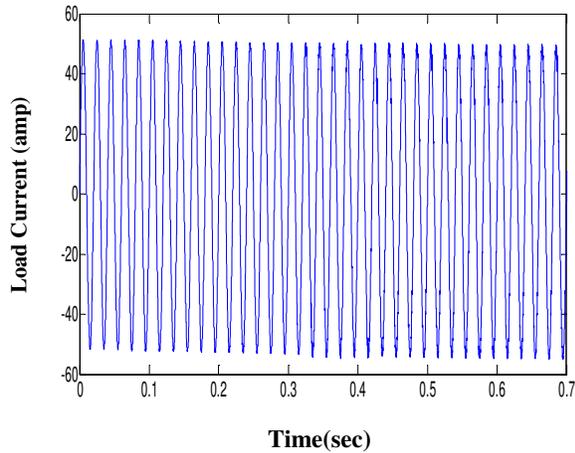


Fig. 5(a) Load Current (amp) on islanding at 0.4 sec.

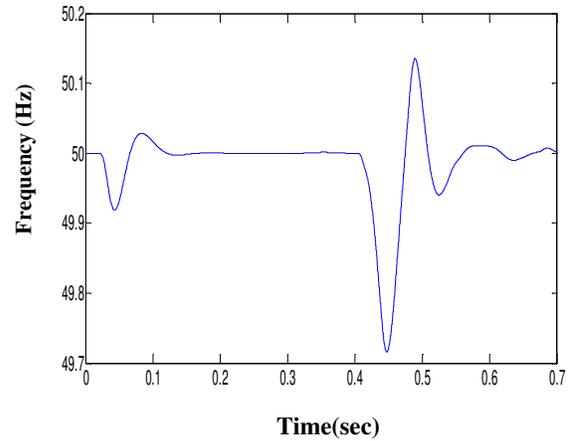


Fig. 5(d) Frequency of voltage at point of common coupling (volt) on islanding at 0.4 sec

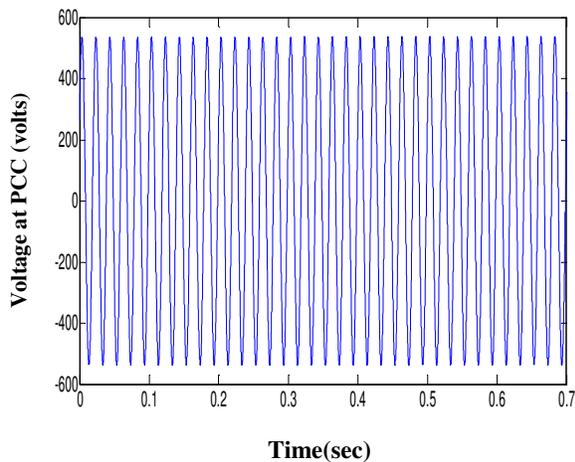


Fig.5(b) Voltage at point of common coupling (volt) on islanding at 0.4 sec

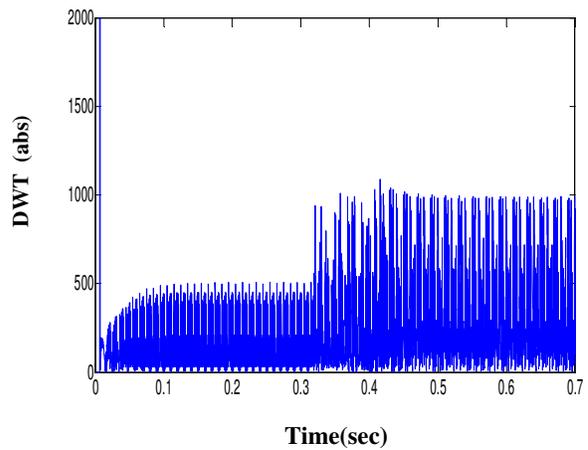


Fig. 5(e) DWT of voltage at point of common coupling on islanding at 0.4 sec

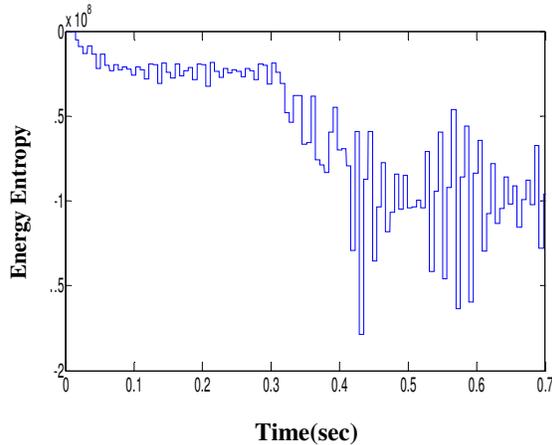
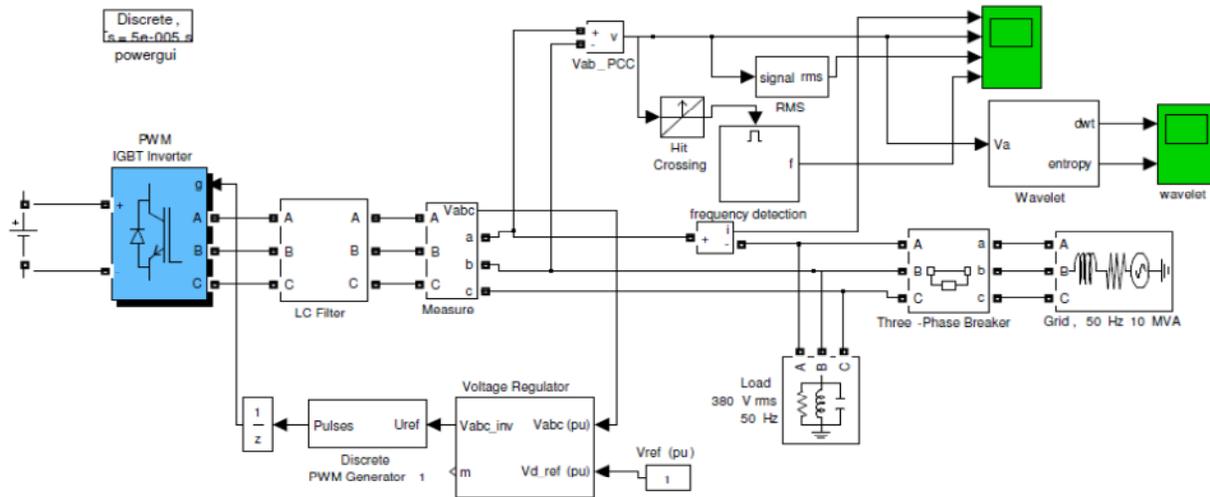


Fig. 5(f) Energy entropy of Voltage at point of common coupling (volt) on islanding at 0.4 sec

A novel method for islanding detection by the analysis of wavelet entropy is presented in this paper. It has been shown that if voltage is measured at point of common coupling and used to calculate wavelet energy entropy then islanding gives a remarkable change in the value of entropy. The effectiveness of this indicator is verified by simulation for zero power mismatch condition. However in some cases of mass load switching and faults, the entropy may change considerably leading to nuisance trip for islanding. Hence it is required to construct more sophisticated hybrid solutions which combine wavelet entropy and an effective active antiislanding technique. By doing this we can avoid the nuisance trip and reduce the excessive disturbance caused by the active method.

6 Conclusions

APPENDIX



SIMULATION MODEL

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