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Analysis of power system parameters for islanding detection using wavelet transform

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ABSTRACT

This paper classifies the basic power system parameters based on sensitivity and performance capability. This is the basic step in selecting the suitable parameter for intelligent islanding detection technique. The behaviour of basic power system parameters is analyzed using wavelet transform under all possible islanding and non-islanding conditions. In wavelet transform, the mother wavelet plays a significant role in the extraction of parameter features. The db4 mother wavelet is selected after an extensive analysis on different mother wavelets. As a result, it has been found that the extracted feature of reactive power shows the highest capability to distinguish islanding from non-islanding events.

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1. INTRODUCTION

The increase in needs and incidences of power outages, power quality issues, and electricity price spikes are the reasons why many utility customers seek different sources of energy. Distributed energy resources (DER) such as solar panels, wind mills, micro-hydro generators, and biomass offers an alternative to the conventional electric power supply. They are positioned near home, commercial, industry or any sort of other locality [1].

DER's are faster, inexpensive choice as compared to central power plants. The benefits include lower price, better service reliability, better power quality, and increased power efficiency [2, 3]. Furthermore, these sources mainly depend on renewable energy, thus providing considerable environmental advantages [4]. However, it causes certain technical challenges such as issues in power quality, islanding, interconnection of DER's to utility grid, and personnel safety. Islanding is one of the most considerable issues. It is a scenario in which the grid gets cut off from the load and the load gets the electric supply merely by the DER's [5]. It possibly risks the workforces, power quality distortion, system stability, supply regeneration and the equipment safety. Hence, making the timely detection of islanding, a necessity. The IEEE standards 929-2000 and 1547-2003 emphasize that this detection time should not be greater than 2 seconds [6].

Islanding detection relays are commonly used to pinpoint the islanding situations. The islanding detection techniques are classified into two main categories viz. local and remote techniques. Local islanding technique consists of passive, active, and hybrid whereas remote consists of communication-based techniques. Passive techniques involve the islanding detection by tracking the system parameters whilst in the active techniques involves the introduction of perturbations at point of common coupling and the decisions are made based on the responses [7]. Hybrid technique involves the combined function of active as well as passive techniques. However, local techniques suffer from large NDZ, threshold setting requirements and distortion in power quality. Communication techniques encompass the essence of communication. Many other techniques, involving signal processing and intelligent-based computation were proposed, each pertaining pros and cons [8, 9].

With the advent of intelligent computation and signal processing techniques, the passive islanding detection techniques are commonly used. For feature extraction, many researchers used multiple parameters which comprise the indices as well as the corresponding derivatives or rate of change (ROC). Faqhruldin et al. [9] utilizes 21 parameters, which exercises 14 indices and 7 ROC. On the other hand, Alam et al. [10] made use of 3 indices and 2 ROC and K. El-Arroudi along with G. Joos [11] employed 2 indices and 2 ROC and 7 indices and 4 ROC respectively are used by [12]. The various intelligent classifiers take these parameters as an input and use it to distinguish islanding condition from the non-islanding scenarios at critical situations, giving rise to the techniques which are highly accurate and depend upon several parameters. The usage of several parameters makes the technique complex. The research gap deduced in this context is that no appropriate method exists for choosing these features or parameters for intelligent islanding detection technique.

Owing to the significance of the intelligent relays, the objective of this work is to understand the characteristics of the passive parameters with respect to response analysis, which has now been essential for the utilities along with the DER owners. This scrutiny will assist the choice of parameters for classifiers to differentiate islanding event as well as the non-islanding conditions. The purpose of this research is to grade different basic power system parameters. To prioritize the parameters, the normally used basic parameters (current, voltage, active power and reactive power) are examined as per their sensitivity, under all possible islanding and the abnormal conditions. Upon observation, it has been found that the reactive power once operated by wavelet transform proves to be the most sensitive as compared to other parameters.

2. WAVELET TRANSFORM

The The Fourier and Short Time Fourier transform techniques were commonly used for feature extraction. However, the Fourier transform is not appropriate for non-stationary signals and it fails for certain frequency rise. Similarly, the low frequency signal transients are not detected by Short Time Fourier transform and ultimately frequency resolution are compromised in both cases [13-15].

The wavelet transform is an improved version of Fourier transform. It is localized in both frequency domain and time domain and this technique can analyze the non-stationary signals [16]. In it, the signal is divided into orthogonal set of frequencies and flexibility increases in time-frequency analysis [17-21]. The Wavelet transform is classified into two types in terms of their operation, continuous wavelet (CWT) and discrete wavelet transforms (DWT)

2.1. Continuous Wavelet Transform

CWT yields a correlation of a finite energy signal with the scaled shifted and delayed version of the mother wavelet. Mathematically, it can be written as (1).

$$CWT(u,s) = \int_{-\infty}^{\infty} f(t)\varphi_{u,s}^{*}(t)\,dt \qquad \text{For } (s > 0, -\infty < u < \infty) \qquad (1)$$

Where, φ is the mother wavelet, u denotes the shifting, s denotes the scaling.

In it, the specific mother wavelet is chosen and convolved with a section of the signal and iteratively a correlation coefficient is calculated by shifting the signal in time domain till the whole signal is recovered. The mother wavelet is then stretched, and the process is repeated until a series of correlation coefficients are obtained.

2.2. Discrete Wavelet Transform

CWT perform convolution operation on the signal, it shifts and stretches the signal in all possible integer factors. The similarity between the mother wavelet and the original signal is analyzed/ measured by using the inner product. It is a time-consuming process because it results in piles of the undesirable coefficients. Furthermore, this large amount of data generation makes it hard to implement [21, 22]. On the other hand, DWT uses down-sampling and get rid of some of the frequency components at specific times without affecting the signal. It helps to analyze the good and bad part of the signal at the same time with comparatively much less number samples as compared to CWT. It is analogous to convolve the signal through high pass filter and low pass filters separating the high frequency component (details) and the low frequency component (approximation). The decomposition tree of DWT is shown in Figure 1 [23].

In this proposed work, discrete wavelet transform is used due to its lesser time consumption and simplicity in implementation. However, the major point of concern is the selection of specific DWT mother wavelet. Normally, different types of mother wavelets are used such as daubechies (Db), Sinc, Spline, Coiflet, Haar, Mexican hat and Bi-orthogonal as shown in Figure 2 [23]. To select the most suitable DWT mother wavelet, the signal from basic power system parameter was chosen and analyzed it in the 1D MATLAB wavelet analyzers under different conditions.

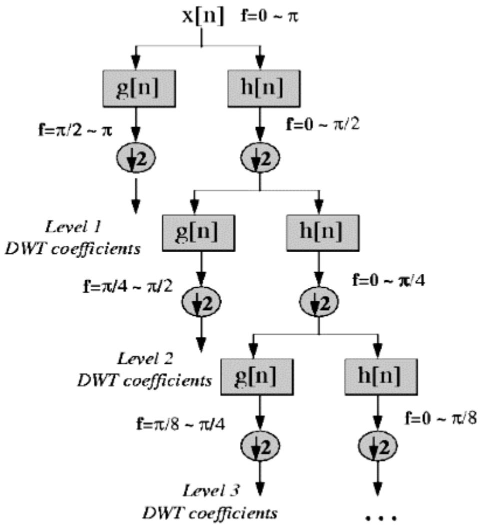


Figure 1. DWT decomposition tree [23]

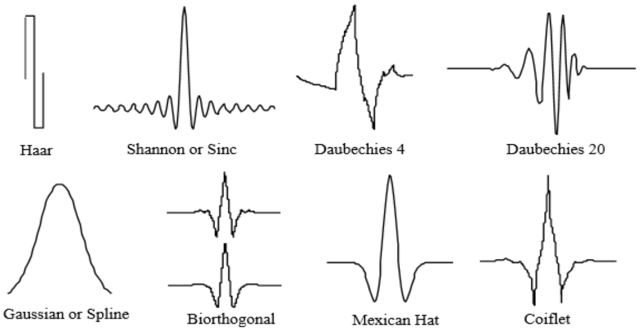


Figure 2. Different mother wavelets [23]

3. SYSTEM MODELING

This work considers an 11 kV distribution system modelled in MATLAB/ Simulink according to IEEE 1547 standard as shown in Figure 3. It includes wind generator (WG), utility grid, 2 circuit breakers, 2 three phase transformers, and three phase RLC loads.

The working of the islanding detection technique is primarily based on the type of load. The IEEE 1547 standard suggests choosing a parallel RLC load to verify the function of islanding detection technique, because it makes things more difficult contrary to other kinds of load. The RLC load is connected to the point of common coupling (PCC). The single line diagram is shown in Figure 4. The IEEE 1547 test frame values for different components are given in Table 1.

Table 1. IEEE 1547 Test Frame

Indices	Value	Indices	Value
Wind Generator	3 MW	Resistance (R)	40.3 ohm
Frequency	50 Hz	Inductance (L)	170 mH
Voltage (L-L)	11 KV	Capacitance (C)	59 uF

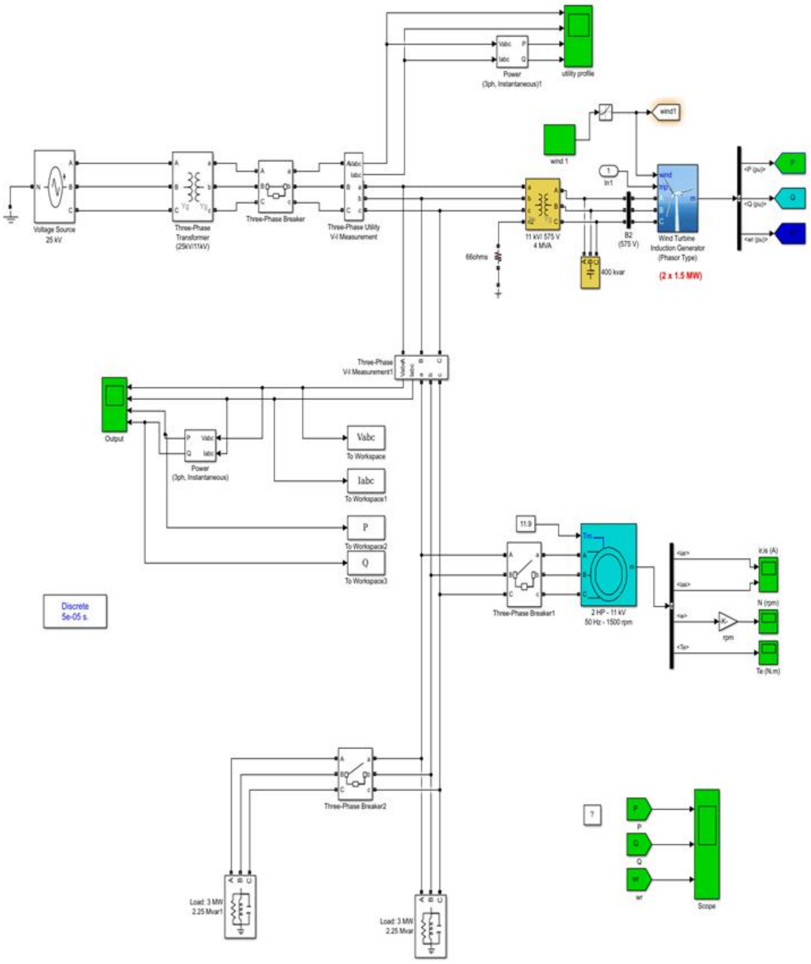


Figure 3. Distribution system under study

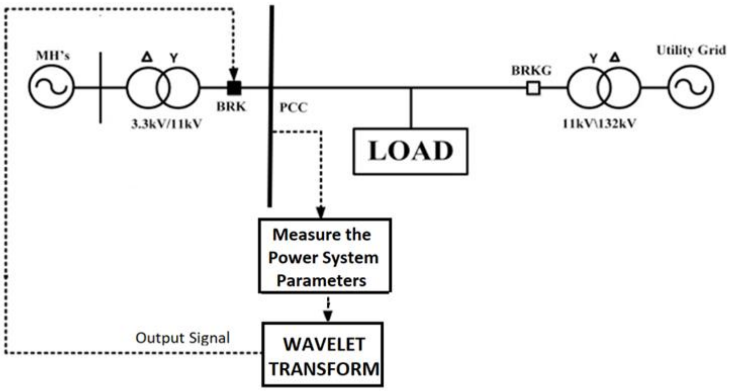


Figure 4. Single line diagram

4. RESULTS AND ANALYSIS

The values of different basic power system parameters, like active power, reactive power, voltage, and current are obtained by simulation. These parameter values are selected for various islanding and non-islanding situations. The non-islanding situations include line to neutral (LN), line to line to Neutral (LLN), line to line to line to neutral (LLLN) faults, load switching instances at different power mismatching between generation and load demands. Firstly, sensitivity analysis has been done using different mother wavelet to select the most suitable mother wavelet and then the islanding and non-islanding conditions are analysed.

4.1. Sensitivity Analysis

The active power signal is analyzed by different mother wavelets of discrete wavelet transform as shown in Figure 5.

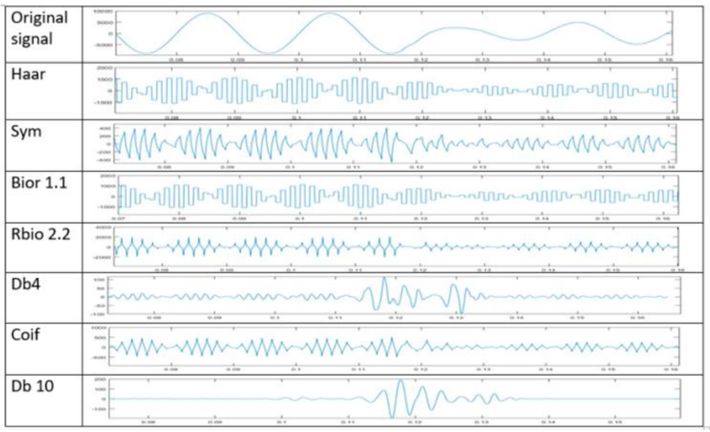
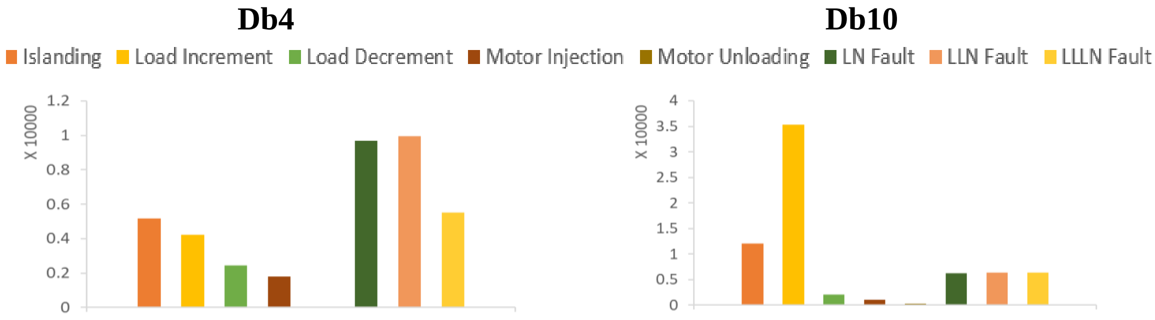
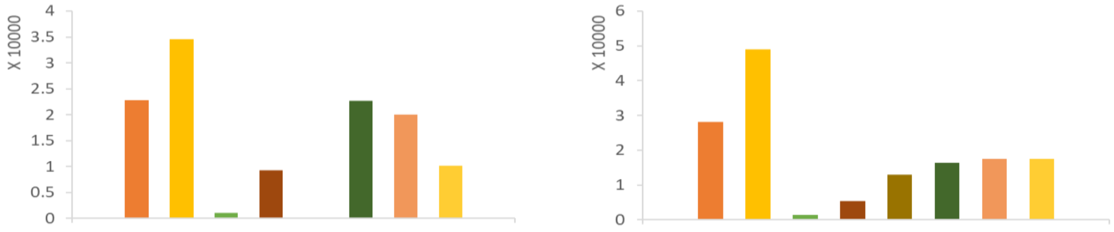


Figure 5. Active power analysis using different DWT mother wavelets

Based on analysis, it has been found that Db 4 and Db 10 mother wavelets show outstanding behaviour. However, for more accurate results, these mother wavelets were further decomposed from level 1 – 9 and active power decomposition accuracy was checked. The comparison of different levels for Db 4 and Db 10 mother wavelets for active power are shown in Figure 6. It is quite clear from Figure 6 that Db 4 at level 9 provides much better results. Hence, Db 4 level 9 is selected for further analysis.



(Level 1) (Level 1)



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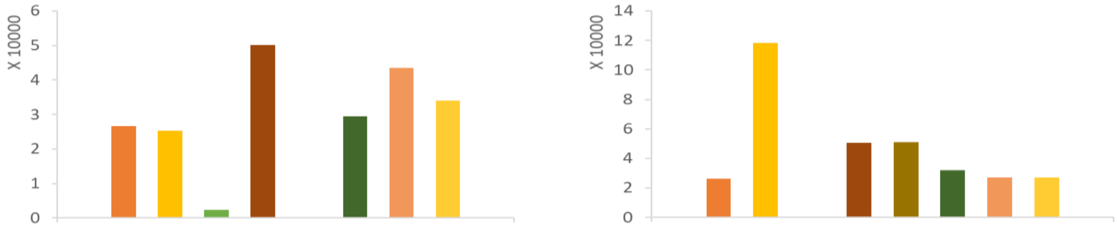

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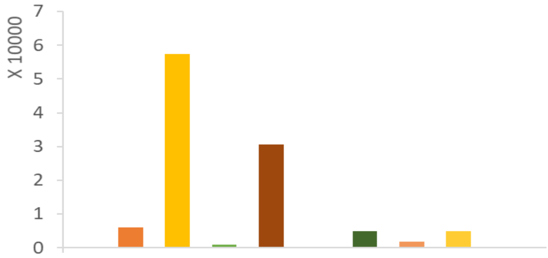

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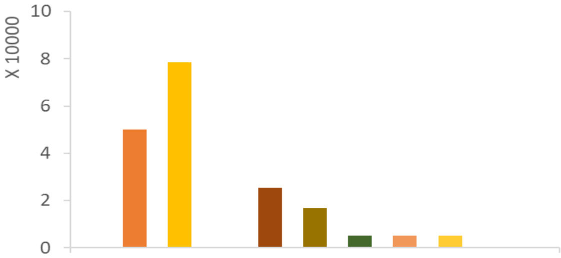

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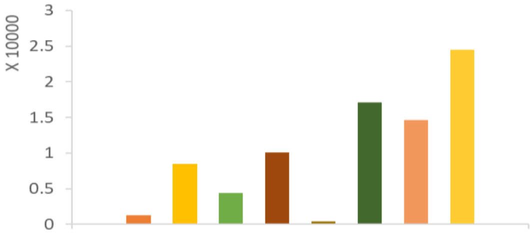

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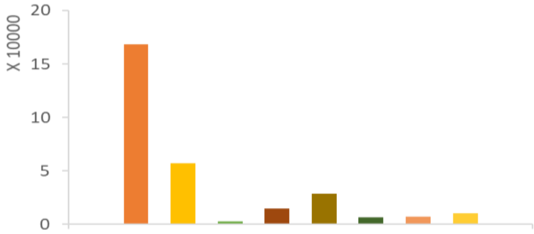

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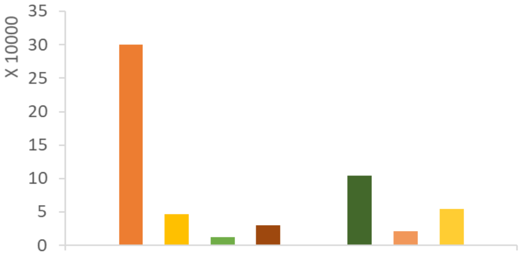

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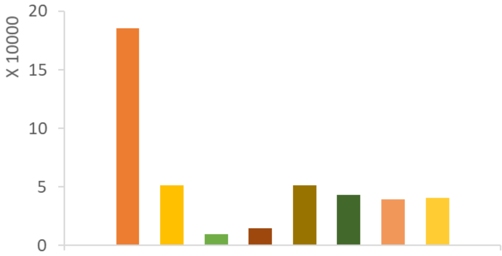

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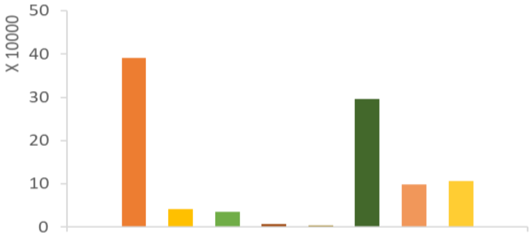

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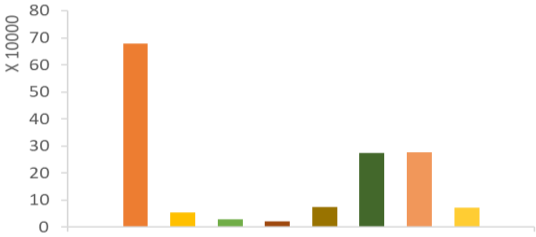

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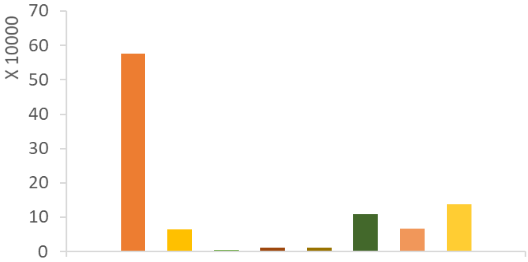

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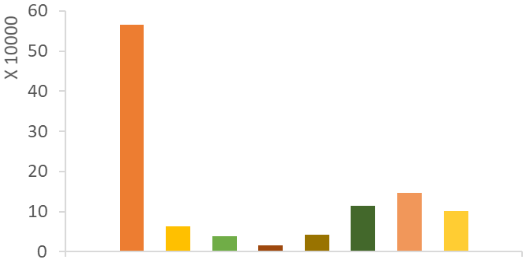

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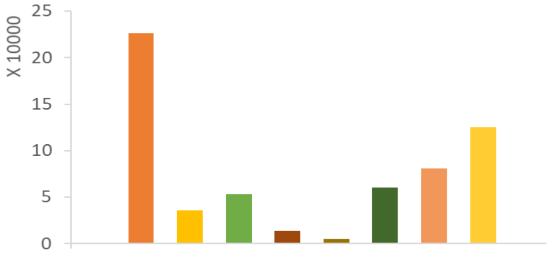

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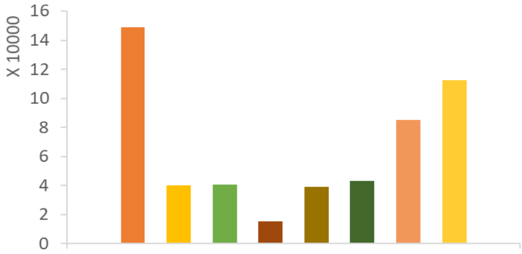

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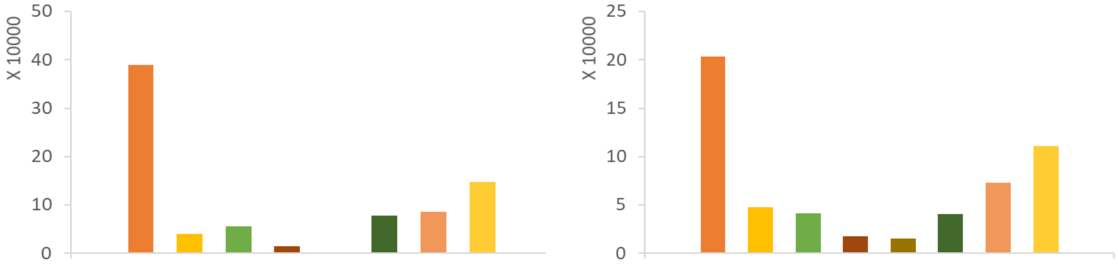


(Level 10) (Level 10)

Figure 6. Comparison of Db 4 and Db 10 mother wavelet at different levels

4.2. Conditions Analysed

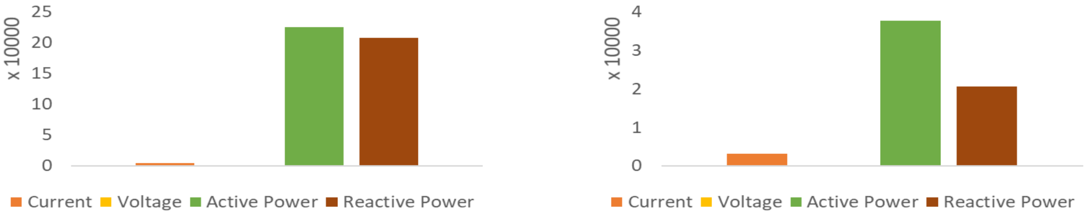
There are numerous conditions which may cause transients in power system parameters [24]. In it, few conditions are quite natural and do not need attention while others need more attention. Such as, the starting torque of the commonly used induction motor draws greater amount of current at starting and then comes to normal [25]. However, islanding condition should be detected as soon as possible. The various cases which are analysed in this work are as follows:

a) Islanding
b) Line to neutral (LN) fault
c) Line to line to neutral (LLN) fault
d) Line to line to line to neutral (LLLN) fault
e) Load increment
f) Load decrement
g) Motor injection
h) Motor unloading

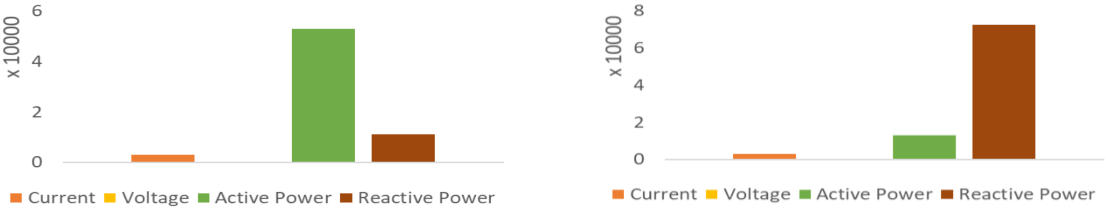
The signals obtained at the point of common coupling (PCC) were analysed using Db 4 level 9 mother wavelet.

4.2.1. Closely Matched Condition

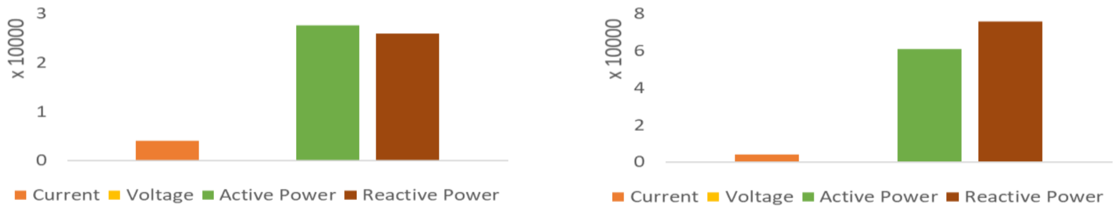
In the closely matched condition, the power generated by the DG closely matches with the power consumption of the load. In the studied case, we set the values for the DG and the load to be 3 MW. Power supplied by the DG is 2.94 MW and grid is responsible to supply the rest of the power. In case of load increment, the load is increased and decreased to 3 MW. The induction motor having capacity of 0.5 hp is switched on and off and responses of basic power system parameters are checked. Furthermore, the different types of faults are also introduced to observe the behaviour of different basic parameters. The results obtained are shown in Figure 7.



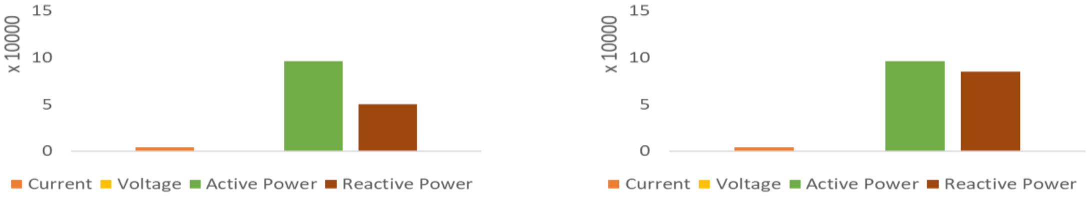
(a) Islanding (b) Load Increment



(c) Load Decrement (d) Motor Injection



(e) Motor unloading (f) LN Fault

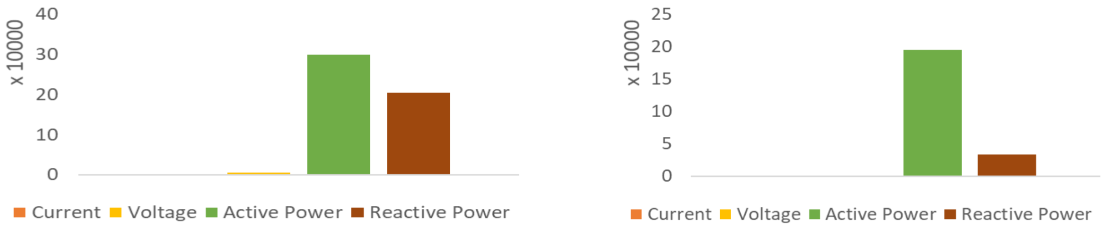


(g) LLN Fault (h) LLLN Fault

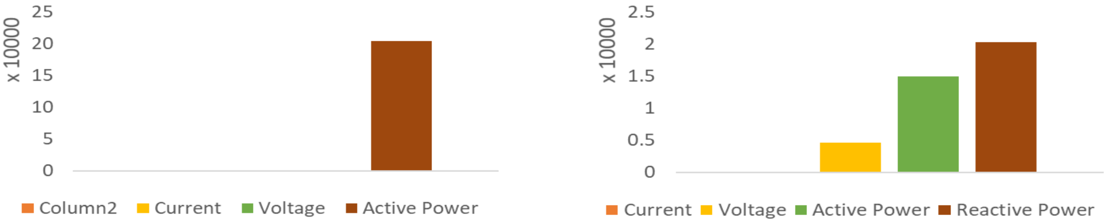
Figure 7. Closely matched conditions

4.2.2. Mismatch Condition

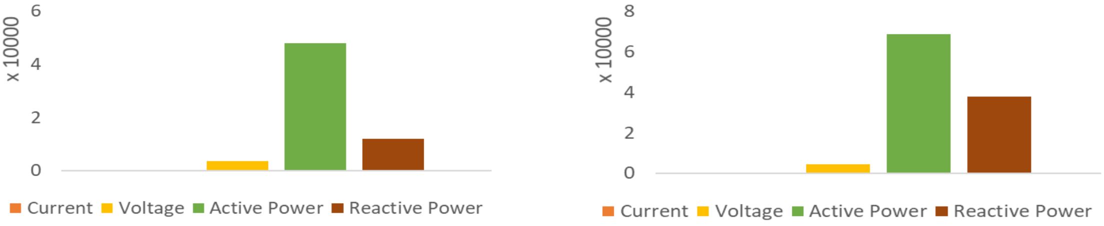
In mismatched condition, there is a difference between the DG and load demand. This indicates that utility is responsible to provide excessive power to energize the remaining load. In this work, the mismatch condition is created by the addition of 1 MW and 1 MVar load. The power supplied by the DG is 2.8 MW and the rest (1.2 MW) is supplied by the utility grid. The islanding condition is observed at this scenario. For load increment and decrement, a load of 3 MW and 3 MVar is further added and the performance of basic power system parameter is observed. Furthermore, induction motor having capacity of 0.5 hp is injected and unloaded and response is recorded. Moreover, fault scenarios are also observed. The results obtained under these cases are shown in Figure 8.



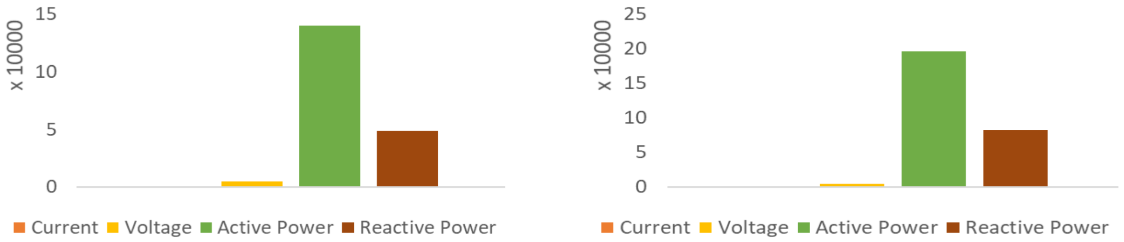
(a) Islanding (b) Load Increment



(c) Load Decrement (d) Motor Injection



(e) Motor Unloading (f) LN Fault



(g) LLN Fault (h) LLLN Fault

Figure 8. Mismatched conditions

5. CONCLUSIONS

In this paper, the prioritization of different basic power system parameters based on performance capability has been presented. The performance capability of these parameters is justified using 11 kV distribution network, modelled under IEEE 1547 test frame for various islanding and non-islanding conditions. The suitable parameter is selected once operated by Db 4 level 9 mother wavelet. The procedure for the selection of specific mother wavelet is also presented. The reactive power once operated by Db 4 (level 9) mother wavelet shows the higher performance capability to distinguish islanding and non-islanding events. Furthermore, this analysis will serve as a guideline for researchers and DG owners in selecting the parameter for intelligent islanding detection technique.

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