Frequency Disturbance Triggered Hybrid Islanding Detection Scheme using Discrete Wavelet Transform and Artificial Neural Networks

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In today's world, Sources of renewable energy (RES) using PV arrays are the most extensively used. When RES is connected to the grid, there will be some issues owing to the unexpected circuit breakers connected to the grid trip, which creates islanding. This islanding condition should be detected within two seconds, as per IEEE standards. This paper presents frequency disturbance triggered hybrid islanding detection using Artificial Neural network (ANN) and Discrete Wavelet Transformation (DWT). The ANN model is trained by these WT features and this approach calculates the detection time for various loading and non islanding conditions. DWT analysis is performed up to level 4 in this work which is fed to an ANN model to predict islanding detection time. Simulation of frequency triggered hybrid islanding detection approach is implemented on the Matlab 2018b platform. Python 3.9.5 is used for the discrete wavelet transform and ANN.

Keywords:ANN, Current injection, frequency disturbance, DWT, Islanding Detection.

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1 Introduction

This Integration of Distributed generators into electrical grid will raise serious concerns about the stability and safe operation of the grid [1-3]. The nature of DG to power local loads even though the electric utility is unable to supply power is called islanding [4-6] Moreover, according to IEEE 1547-2003 standards, detection of islanding condition has to be done within 2 sec of its occurrence [7].Islanding detection schemes are broadly divided as active, passive and hybrid [8-9].Operation of passive islanding methods depends on the information available on the DG side which helps to detect islanding conditions. Active islanding schemes are based on periodic perturbation signal transmission between grid and DG to determine islanding detection and these techniques have less NDZ. Hybrid islanding detection techniques are far more effective than other islanding detection techniques. But these are complex and costlier [10].

2 Test system and Methodology

The test system details are in Table. 1 [11].It generally consists of grid which is connected to DG with a parallel RLC load using a synchronous phase-locked loop (PLL) as shown in Fig. 1. To operate DG in constant power control mode, switching pulses are required for VSC which are generated with a pulse width modulation (PWM). Discrete PLL blocks are used to measure the frequency deviation at DG (f_{DG}) and grid side (f_G). If frequency deviation (f_d) exceeds threshold value (Th_1) then output pulse will be sent to the PWM controller to initiate disturbance current injection using the current controller

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Table 1. List of Parameters

S.No	Variable	Values
1	PV Array	P_{max}: 100 kW at 1000 W/m^2 sun irradiance.
2	Grid Voltage	125-kV distribution feeder + 120 kV equivalent transmission system
3	DC-DC boost converter	Step up 273 V DC to 500 V DC.
4	3-phase Voltage Source Converter	Convert link voltage of 500 V DC to 260 V AC at unity power factor.
5	Sampling time	100 microseconds

A current with a low frequency of disruption (i_d^*) will be introduced after occurrence of disturbance event. It is 1% of inverter DG current and the introduction will be done through the d-axis for a period of time current controller with 0.3 sec as represented in Fig.2 [12-13].

$$i_d^* = ki_d cos(w_d t) \qquad (1)$$

Where i_d=d-axis current;k =constant its value is lies between 0.01 -0.03;w_d= disturbance current frequency

Fault detection parameters are identified by a passive islanding parameter called Rate of change of phase angle between positive sequence voltage and current (RCPABPSVAC). It will be hard to analyse currents of DG terminal and voltages in the abc-Reference frame. Due to the difficulty of analysing DG voltage and current signals in abc frame, these quantities will be converted into dq reference frame. Circuit breakers are placed at both DG and grid sides to simulate islanding conditions and also to isolate DG at the instant of islanding. DWT analysis is done up to level4 to generate various wavelet coefficients. ANN model algorithm is utilized to determine fault detection time for various fault conditions under grid-connected mode [14].

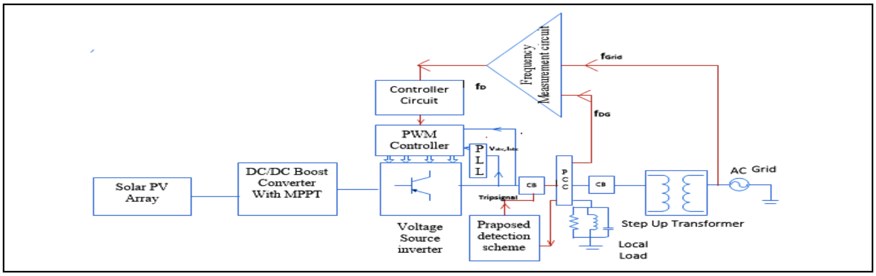


Figure 1. Test system block diagram

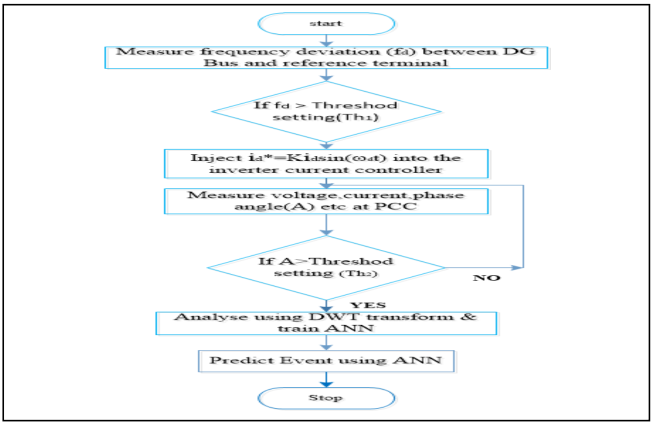


Figure 2. Test system Flowchart

2.1 Transformation of Discrete Wavelets

Signal and speech processing applications are best served by wavelet transforms and ANN. A wavelet transform consists of the location and scale of two basic components. A wavelet transform consists of a succession of wavelet functions of various sizes. The HPF and LPF can be used to create lower resolution components. The wavelet transform is separated into two types, continuous (CWT) and discrete (DWT). A signal's CWT can be written as

$$(v,x,y)=\frac{1}{\sqrt{a}}\int_{+\infty}^{-\infty} v(t)\psi^{*}\left(\frac{t-y}{x}\right) \qquad (2)$$

In this equation, x is the scale (dilation) constant, while y is the translation (time shift) constant, and the mother wavelet is denoted by ψ^*
A signal's DWT can be written as

$$(\mathrm{v,x,y})=\frac{1}{\sqrt{x_0^m}}\sum_k v(k)\,\psi^*\left(\frac{n-kx_0^m}{x_0^m}\right) \qquad (3)$$

The integer variables x_0^m and kx_0^m, are used to replace the x and y terms in equation 3.
The HPF preserves signal properties in the wavelet function, whereas the LPF represents the coarser information of the approximation signal. In this procedure, the Daubechies level 4 filter is used by DWT analysis (d-4).

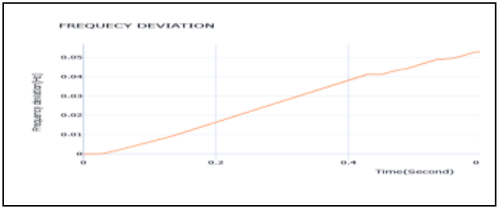
2.2 DWT Analysis & ANN

In general, PyWT. dwt applies to all islanding data at a single level. During a single-level discrete wavelet transform, Haar or d-1 is used. For multilayer discrete wavelet transforms up to level 4, the Pywt.wavedec function is utilized. The selection of hidden layers has a big impact on the ANN's output accuracy prediction.100 epochs are used during the ANN model of momentum rate 1msec/step. ReLU, Sigmoid is used as transfer functions of ANN input, hidden and output layers. ANN models take into account the WT indices in order to detect faults more accurately, based on the differences reflected therein. The data set consists of 25001 samples. In the cross-validation technique, the simulated divided as training data of 20000 (70% of samples) samples and testing data of 5001 samples (30% of samples). During DWT analysis these samples are finally reduced to 1563 samples of which training data has 1250 samples and testing data has 313 samples at level4. So with the decrease in the number of samples the stochastic algorithm will easily predict islanding detection at faster rate. The objective of the learning process is to achieve the smallest mean square error possible. The hidden layer neurons were changed till the mean square error (MSE) was reduced [15].

3 Results and Discussion

The occurrence of islanding was initiated at 0.2 seconds in all of the case studies below by tripping the circuit breaker on the grid side and the frequency of the micro grid begins to vary from grid frequency after the islanding instant. As a result, starting at t=0.3525sec, the difference in frequency parameter begins to diverge from zero, as seen in Figure 3(a). However, because the d-axis voltage is a local measurement, it begins to change at t=0.2sec, as illustrated in Figure 3(b). As the f_d approaches Th_1 (0.33), disturbance current is injected through the inverter current controller for a brief period of 0.3 seconds. During this period, if the Rate of change of phase angle value surpasses threshold value Th_2(0.02 pu) islanding will be identified as shown in Figure 3(c). As a result, trip signals are generated for various power mismatch situations as shown in Figure 3(d). The proposed methodology is implemented using Matlab/Simulink. Analysis of Discrete Wavelet Transform is performed Python programming is used up to level 4 and the ANN Methodology is employed for numerous case studies to predict islanding. Figure 3(a)-(d) to Figure 7(a)-(d) represent frequency deviation, d-axis voltage, Rate of change of phase angle at DG, trip signal generated at DG side circuit breaker. Similarly, Figure 3(f)-(i) to Figure 7(f)-(i) represent Daubechies wavelet Approximate and Detailed coefficient upto level 4 for various fault conditions

A. Conditions of normal loading



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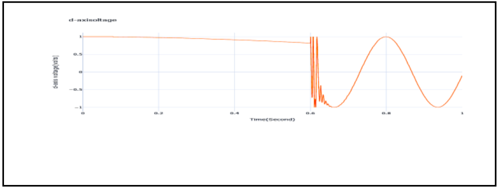

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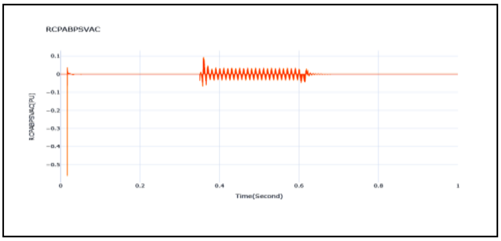

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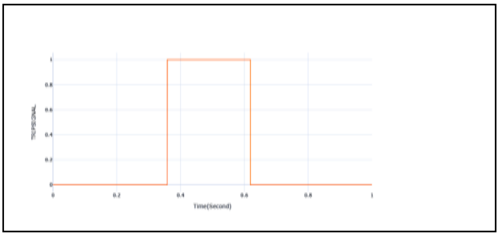

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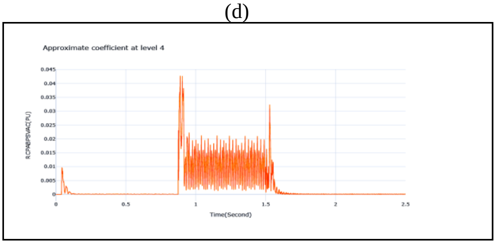

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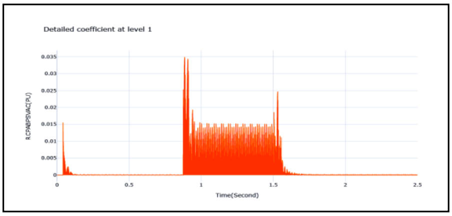

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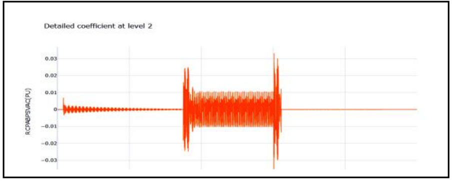

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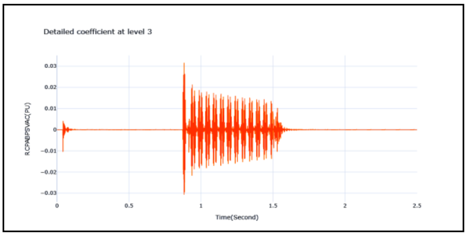

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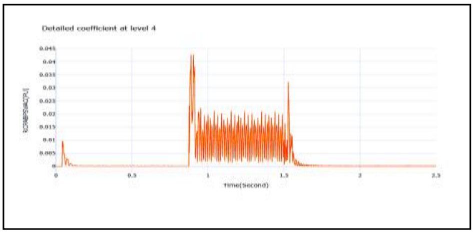
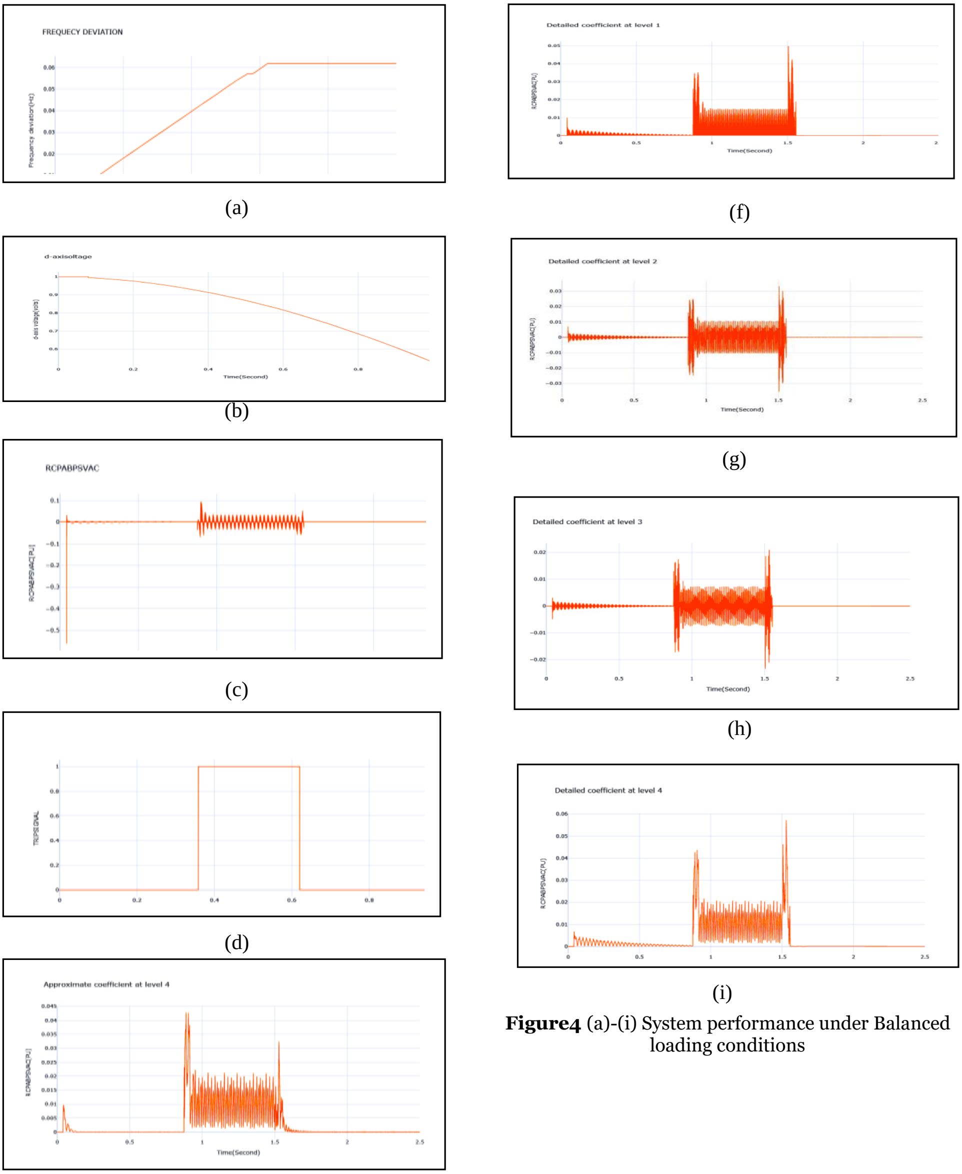


(i)

Figure3.(a)-(i) System performance normal loading conditions

B. Balanced loading Conditions



(a)

(b)

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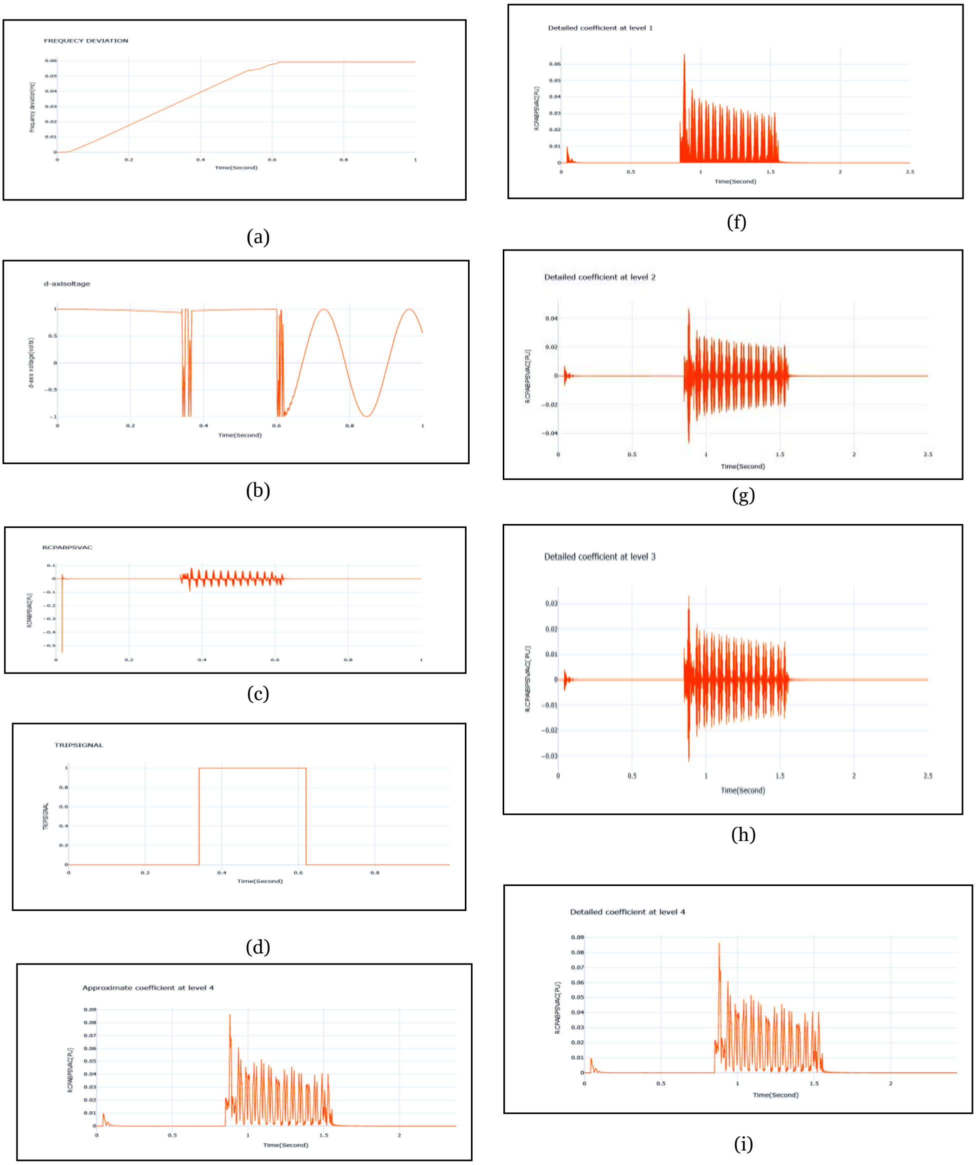
Figure4 (a)-(i) System performance under Balanced loading conditions

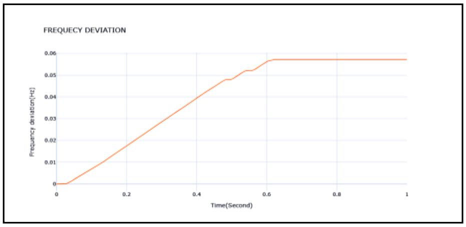
C. Over loading Conditions



(a) (b) (c) (d) (e) (f) (g) (h) (i)

Figure5 (a)-(i) System performance under Over loading conditions

D. Switching conditions of Inductive Load(50HP)(Non islanding)



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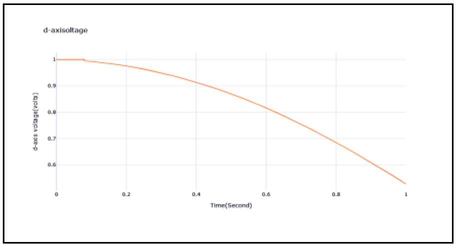

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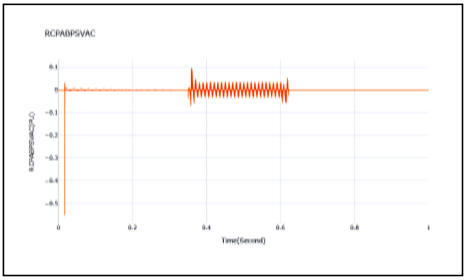

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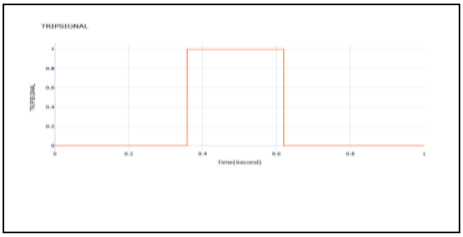

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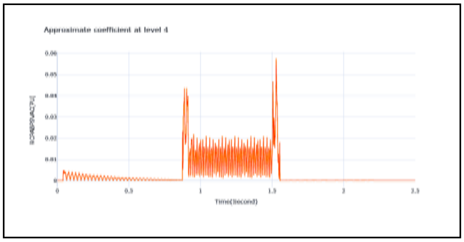

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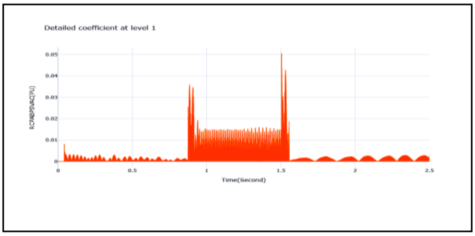

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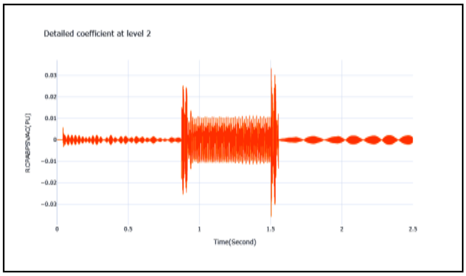

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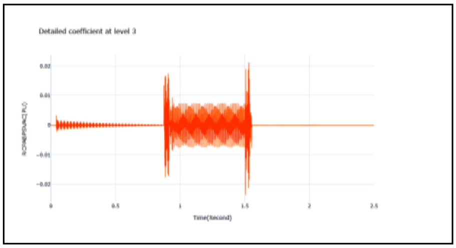

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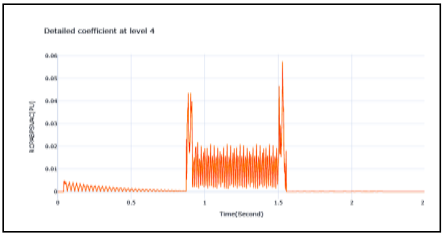
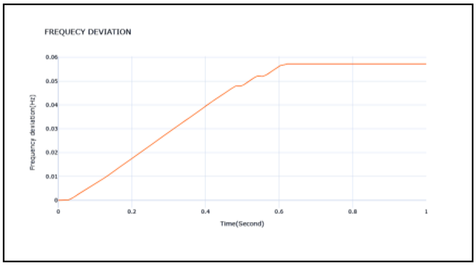


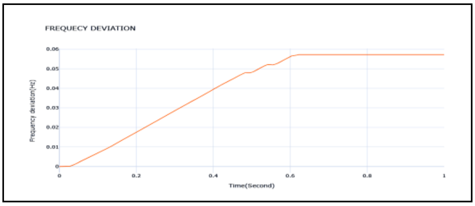
(i)

Figure.6 (a)-(i) System performance under inductive load switching

E Switching condition of capacitor(10KVA)(Non islanding)



(a)



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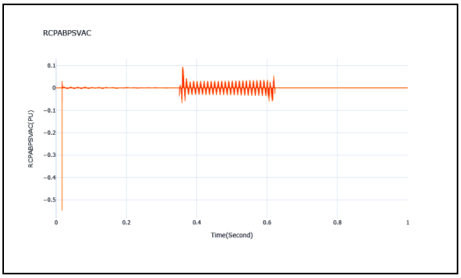

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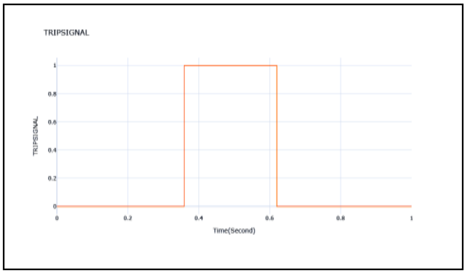

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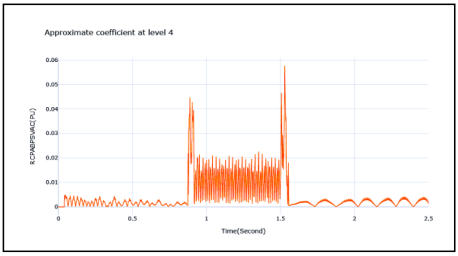

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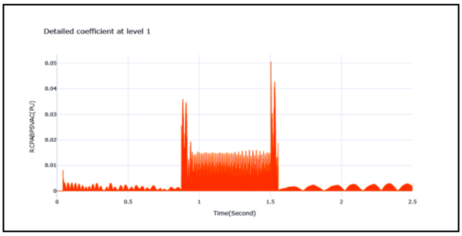

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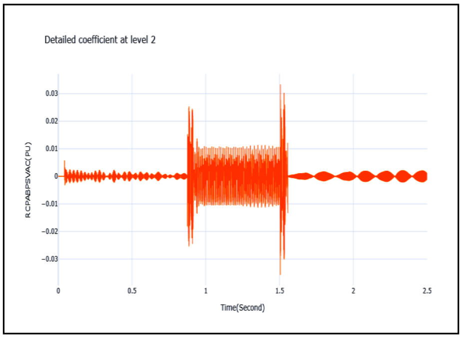

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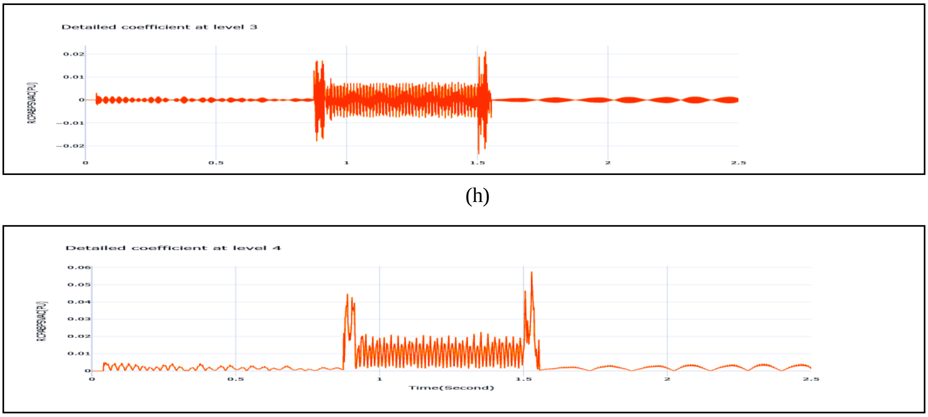

(h)

(i)

Figure.7 (a)-(i) System performance under capacitor switching

4 Comparative Assessment

In this paper, DWT-ANN based frequency disturbance triggered passive islanding detection scheme gradually decreased at level4 below 18msec due to a reduction in the number of samples. MSE also determined for various case studies, lower the value of MSE better will be the accuracy. As shown in Table 2, the results are based on the minimum square error for each case study. The injected current in the current controller has not produced sinusoidal d-axis voltage during both balanced and non islanding conditions which will affect islanding detection time. So, this method detects islanding even under balanced load conditions also. Table 3 indicates the proposed method has better detection time compared to existing procedures. The range of F1-score, Recall, and Precision values are 0.9703,1.9424 at 70KW load. F1-score ranges at 100KW load include Recall; precision is stated as 0.9703,1,0.9744. The ranges of F1-score, recall, and precision value for 120KW load are 0.9834, 0.9908, and 0.9569 respectively. During non-islanding, F1-score, recall, and precision are 0.89422,1.0,0.9744

Table 2. Detection of Islanding in a variety of case studies

Case studies	Normal Detection time(msec)	MSE (at level4)	Accuracy testing data (%)	WT-ANN Detection time(msec) (at level4)
70KW Load	60.4	0.0415	99.85	14.9
100KW Load	116.7	0.05750	94.24	16.98
120KW Load	159	0.04472	97.52	16.54
Inductive Load Switching	105.6	0.057509	94.24	17.86
Capacitor Switching	117.6	0.0575	94.24	17.89

Table 3. Suggeseted approach against existing methods

Approach	Islanding estimation time(msec)
Rate of change of frequency[11]	500
Positive sequence voltage and current [31]	100
Active rate of change of frequency [9]	200
Regulator voltage over reactive power [23]	300
Proposed Technique	Less than 20

5 Conclusion

The research provides a negative sequence islanding detection technique based on WT-ANN that utilizes Mean Square Error to detect islanding conditions for various wavelet coefficients. A performance measurement of 88-92 percent with improved accuracy, F1-scores, recall values during DWT analysis under varied loads. In balanced conditions with 0% NDZ, the suggested islanding technique can also detect islanding and overload conditions in a short amount of time. Advanced ANN approaches such as multiple regressions, recurrent neural networks and others can be used to implement the recommended approach for detecting islands without sacrificing accuracy in the future.

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