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A NOVEL METHOD FOR DETECTION OF DISTURBANCES IN UTILITY NETWORK PRODUCED DUE TO POWER SYSTEM OPERATIONS USING SQUARED WAVELET COEFFICIENTS

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ABSTRACT

The power quality of electric power has become an important issue for electric utilities and its customers. The power system operations introduce disturbances and transients in the network which affects the quality of supplied power. There is need of efficient and economic technique for detection of such disturbances to maintain the quality of power and development of suitable protection techniques to protect the system from abnormal conditions resulted due to these disturbances. This paper presents a novel method for detection of disturbances in the utility network produced due to power system operations using discrete wavelet transform (DWT) based multi-resolution analysis technique. The squared wavelet coefficients (SWC) are used for detection of power system disturbances. A test system having generation, loads, transformers and transmission lines and connected to the utility network through Island Interconnection device (IID) switch is modeled in MATLAB/Simulink environment. The MATLAB programming is used for DWT analysis of the disturbances.

KEYWORDS: Discrete Wavelet Transform, Power System, Squared Wavelet Coefficient, Switching Transient, Transmission Line, Islanding, Synchronization, Transmission Line Fault

1. INTRODUCTION

Power system network consists of transmission and distribution lines used to transfer electrical power from generating stations to load centers, generators and linear/non-linear loads. Power system switching such as sudden outage of load, connection of load with utility grid, islanding, synchronization, etc., are unavoidable in power network and produces disturbances and transients in the system [1]. Such events and disturbances in the power system voltage or current waveforms can be detected by just examining the waveform with an expert eye [2]. Many mathematical detection techniques for these disturbances have been developed based on the fact that many of the problems associated with electric systems develop over time or instantaneous in nature [3].

The probabilistic neural network (PNN) classifier based on S-transform for detection and classification of disturbances in the power system is proposed in [4]. The features extracted through S-transform are trained through PNN for automatic classification of the disturbances. A wavelet packet transform based approach for detection of stationary or non-stationary disturbances in balanced and unbalanced three-phase system is reported in [5]. Empirical mode decomposition with Hilbert Transform for disturbance assessment in power system is proposed in [6]. A novel approach for detection and classification of power system disturbances using discrete wavelet transform and wavelet networks is presented in [7]. The distorted waveforms are generated based on the IEEE 1159 standard, captured with a sampling rate of 20 kHz and de-noised using discrete wavelet transform to obtain signals with higher signal-to-noise ratio.

This paper presents, a discrete wavelet transform based approach for detection of disturbances and transients in utility network during switching conditions that are part of system operation. The detection process is performed through signal decomposition using db4 as mother wavelet. In this paper, we have used the squared wavelet coefficients for the detection purpose. Sum of absolute values of detail coefficients are also used for detection of disturbances in the system. The FFT is carried out for detection of presence of harmonic components and deterioration of the voltage signals.

This paper is organized into six sections. Starting with an introduction in section 1, the section 2 covers the discrete wavelet transform analysis for detection of disturbances and section 3 describes the proposed power system model. Section 4 includes proposed algorithm for detection of disturbances during power system operations and the simulation results and their discussion are presented in section 5. Finally the concluding remark is included in the section 6

2. WAVELET TRANSFORM ANALYSIS FOR DISTURBANCE DETECTION

The digital signal processing techniques are widely used for processing the signals associated with power system. These techniques have been classified into two categories, the frequency-based and time-frequency techniques. The frequency based techniques, such as Fourier transform, are used for stationary signal analysis. The time-frequency based techniques, such as short- time Fourier transform (STFT), wavelet transform (WT), ambiguity function (AF), and wigner-ville distribution (WVD) are usually used for extracting transient features from the non-stationary signals [8]. The wavelet transform is a mathematical tool, much like a Fourier transform in analyzing a stationary signal that decomposes a signal into different scales with different levels of resolution by dilating a single prototype function. The decomposition into scales is made possible by the fact that the WT is based on a square-integrable function and group theory representation. The wavelet transform provides a local representation, in both time and frequency, of a given signal. Therefore, it is suitable for analyzing a signal where time-frequency resolution is needed such as disturbance transition events during faulty conditions in the transmission lines [9]-[10].

The discrete wavelet transform (DWT) is the basic tool for the feature extraction. DWT is the discrete counter part of the continuous wavelet transform (CWT). The CWT of a continuous time signal is defined as [11]

$$CWT(a,b) = \int_{-\infty}^{+\infty} f(t)\psi_{a,b}^{*}(t)dt, a,b \in R, a \neq 0 \quad (1)$$

and $\psi_{a,b}^{*}(t) = \frac{1}{\sqrt{|a|}}\,\psi^{*}\left(\frac{t-b}{a}\right)$ (2)

where $\psi(t)$ is the mother wavelet, the asterisks denote complex conjugates, a and b are scaling and translating parameters respectively.

For detection of transmission line faults, the DWT is used instead of the CWT. This is implemented by using discrete values $a = a_0^m$ and $b = nb_0a_0^m$ for the scaling parameter and translation parameter, respectively. Then, the mother wavelet is given as

$$\psi_{m,n}(t) = a_0^{-\frac{m}{2}}\psi(a_0^{-m}t - nb_0), m,n \in Z \quad (3)$$

Where m and n indicate the frequency localization and the time localization, respectively. When a_0=2 and b_0=1 are used, then the WT is known as dyadic-orthonormal wavelet transform and basis for multi-resolution analysis (MRA).

In MRA, signal is passed through a series of high pass filters (HPF) to analyze the high frequencies, and it is also passed through a series of low pass filters (LPF) to analyze the low frequencies. The signal (S) is decomposed into two types of components: approximation (A) and detail (D). The approximation is high scale, low frequency component of the signal. The detail is low scale, high frequency component. The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal into many lower resolution components which is called the wavelet decomposition tree as shown in Figure 1 [12]. The LPF and HPF filters form a family of scaling $\phi(t)$ and wavelet $\psi(t)$ functions as given below.

$$\phi(t) = \sqrt{2}\sum_n h(n)\phi(2t-n) \quad (4)$$

$$\psi(t) = \sqrt{2}\sum_n g(n)\psi(2t-n) \quad (5)$$

Where $g(n) = (-1)^n h(1-n)$, h is low pass filter and g is high pass filter.

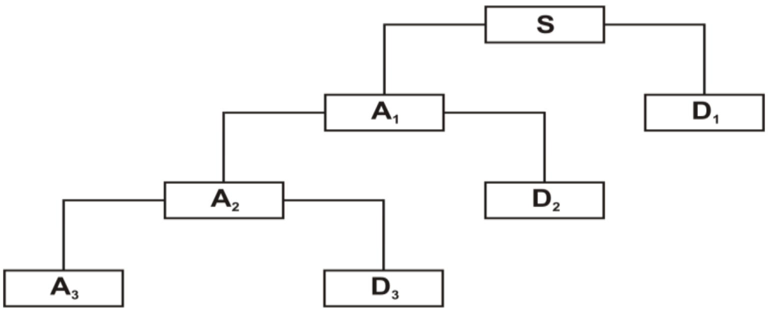

Figure 1: Wavelet Decomposition Tree

The choice of filters h and g with four coefficients is known as daubechies wavelet with four filter coefficients (or Daub4). Daub4 wavelet and Daub4 scaling functions are shown in Figure 2. The proposed study uses squared wavelet coefficients (SWC) for detection of disturbances during power system operations. The SWC have been effectively used for detection of power quality disturbances in [13].

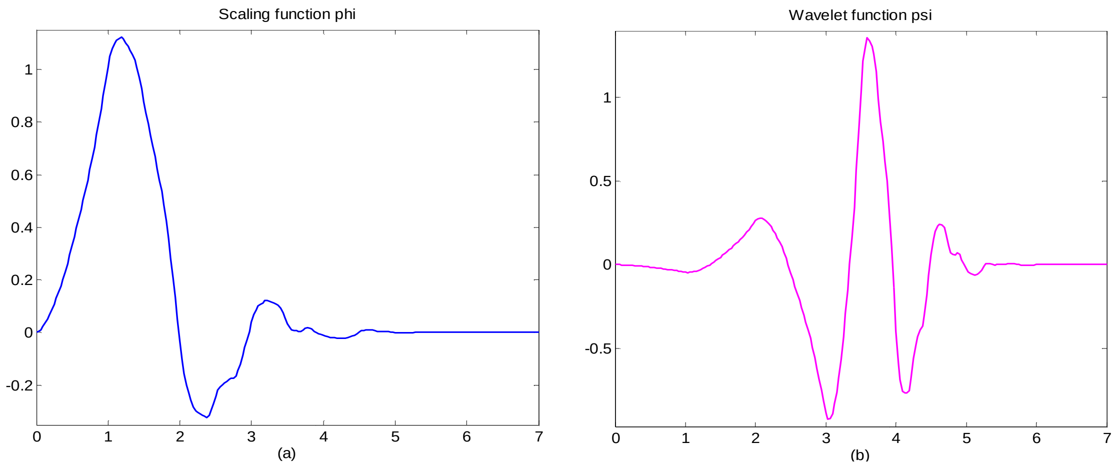

Figure 2: (a) Daub4 Scaling Function and (b) Daub4 Wavelet Function

3. PROPOSED POWER SYSTEM MODEL

The single line diagram of the test system along with utility grid shown by G-2 is shown in Figure 3. The test system transmission line parameters are given in Table 1. The transmission lines of distributed parameters with two sections of 300 km length each are used. In transmission lines, the positive and negative sequence parameters are same; therefore, only positive sequence parameter values are given in the table. The details of transformers T-1 and T-2 are given in Table 2. The load and generator data are given in Table 3. The supply frequency used is 60 Hz. The voltage signal for feature extraction of disturbances is captured at bus 2 of test system.

Table 1: Test System Transmission Line Parameters

S. No.	Attributes	Value
1	Positive sequence resistance R1 (**Ω**/km)	0.01273
2	Zero sequence resistance R0 (**Ω**/km)	0.3864
3	Positive sequence inductance L1 (H/km)	0.9337e-3
4	Zero sequence inductance L0 (H/km)	4.1264e-3
5	Positive sequence capacitance C1 (F/km)	12.74e-9
6	Zero sequence capacitance C0 (F/km)	7.751e-9

Table 2: Transformer Parameters

Transformer	MVA	kV-High	kV-Low	HV Winding		LV Winding	
				R (pu)	X (pu)	R (pu)	X (pu)
T-1	2100	735	13.8	0.002	0.08	0.002	0.08
T-2	300	735	230	0.002	0.15	0.002	0

Table 3: Load and Generator Data

Name of Load	Magnitude	Remark
L-1	100 MW	Star-grounded
L-2	330 MVA	Star-grounded
L-3	330 MVA	Star-grounded
L-4	250 MW	Star-grounded
G-1	2100 MVA	3-wire star

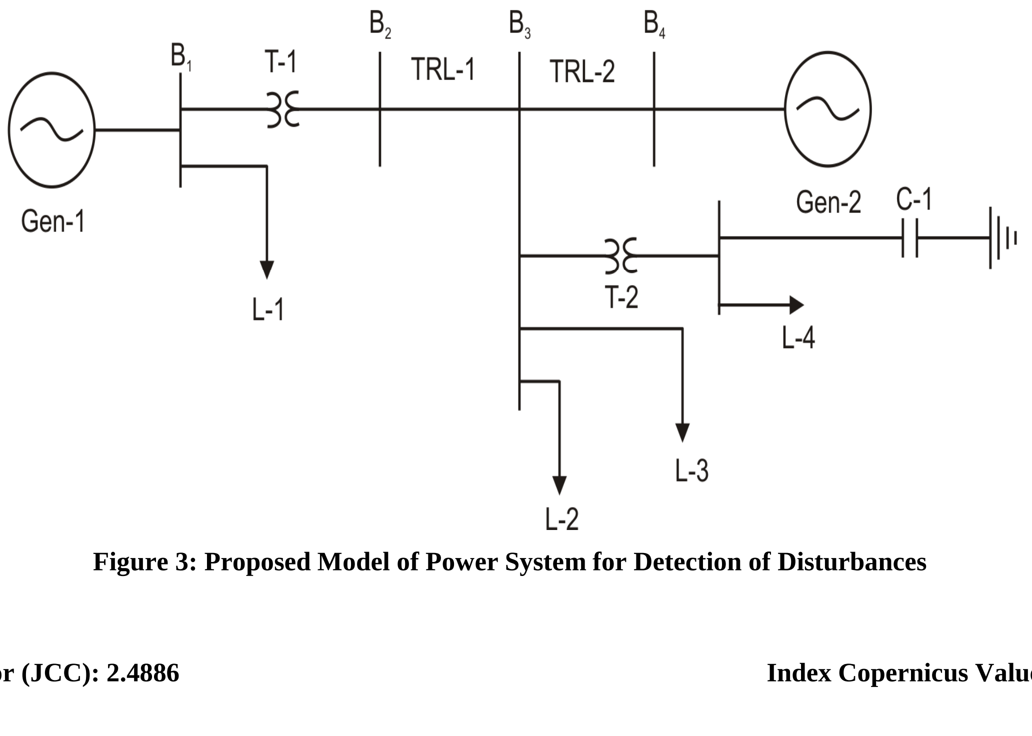

Figure 3: Proposed Model of Power System for Detection of Disturbances

4. PROPOSED ALGORITHM FOR DETECTION OF DISTURBANCES DURING POWER SYSTEM OPERATIONS

The power system operations produce disturbances in the network which may be in acceptable limits and in certain conditions their value increases which may affect the power system stability and tripping of the healthy parts of power system [14]. The power system, disturbances which are abnormal events which are not part of normal operation and unwanted by the network operator must be detected. During normal operating conditions the currents and voltage of the power system are sinusoidal signals. Load variation with time may produce low amplitude changes in current signals and, in lesser extent, in voltage signals. The disturbances in system introduce abrupt changes of amplitude and phase in current and voltage signals [15]. The travelling waves generated due to disturbances in the system arrives at the substation bus bar, it will change incisively, i.e. travelling wave head will present the sudden change in the time-frequency diagram. In that way, travelling wave arrival to the measuring point (usually the busbar voltage transformers) is exactly a moment of sudden change recorded on measuring substation [16]. The system is simulated in MATLAB/simulink environment. The power system operations are performed. The detected three phase voltage signals at bus no. 2 are passed through DWT with db4 as mother wavelet and different details up to level 4 and approximation at level 4 are obtained. The sampling frequency of 1920 Hz is used for DWT decomposition. The squared wavelet coefficients are plotted in each case. The FFT is also carried out to confirm the presence of harmonic components in the voltage signal.

5. SIMULATION RESULTS AND DISCUSSION

The power system model shown in Figure 3 is simulated in MATLAB/Simulink environment with different power system operations such as sudden outage of load, sudden connection of load to the system, islanding of test grid from utility grid, synchronization of test grid with utility grid and three phase faults on power system. The voltage signal of phase-A, is passed through DWT with db4 as mother wavelet and decomposed up to level 4. The squared wavelet coefficients (SWTC) are plotted in each case. The sampling frequency of 1920 Hz is used for wavelet decomposition. The summation of all wavelet coefficients at particular level is also calculated and tabulated separately in each. The frequency components associated with different wavelet coefficients are, with detail at level 1 are 960 Hz-480 Hz, detail at level 2 are 480 Hz-240 Hz, with detail at level 3 are 240 Hz-120 Hz, with detail at level 4 are 120 Hz-60 Hz and with approximation at level 4 are 60 Hz-0 Hz. To detect the presence of harmonic components and deterioration of the voltage signal due to power system operations, the fast Fourier transform (FFT) is carried out and the dominant harmonic components present in the signal and total harmonic distortion (THD) are tabulated separately in each case. The FFT is carried out up to 15^{th} harmonic components. In this study, the harmonic components with value higher than 1% are considered as dominant harmonic component.

5.1. Sudden Load Outage

The voltage signal of phase-A at bus 2 with sudden outage of load L-3 on bus B-3 and squared wavelet coefficients up to level 4 and approximation coefficient at level 4 are shown in Figure 4.

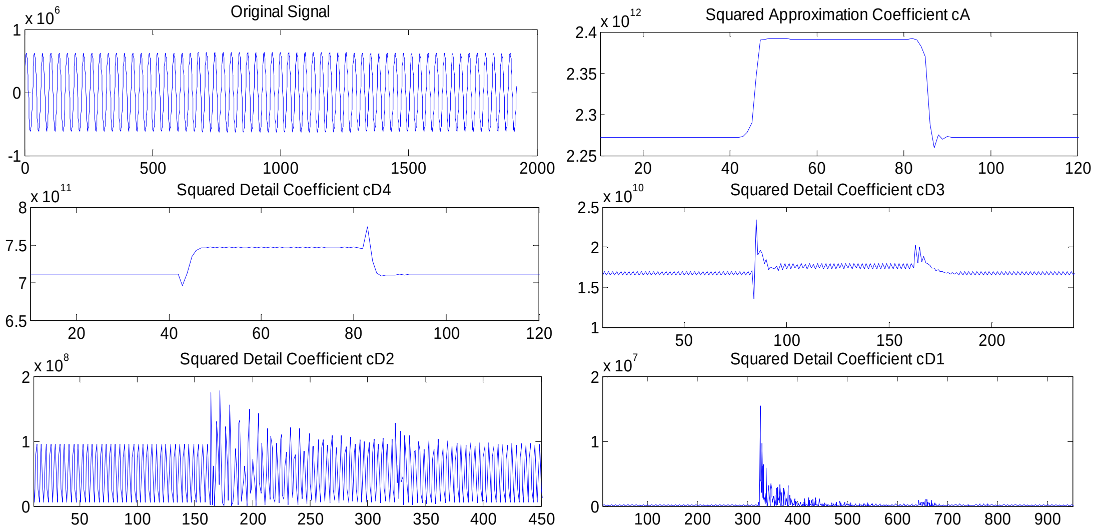

Figure 4: Squared Wavelet Coefficient of Voltage Signal of Phase-A Using Db4 as Mother Wavelet with Sudden Outage of Load

The sudden outage of load is detected at level 1 with high value of squared wavelet detail coefficient.

The detection is also observed at levels 3 and 4. The sudden outage of load produces voltage swell in the system which is detected in the detail at level 3 and 4 as well as approximation at level 4. Harmonic transients are detected by the details at level 1 and 2. High value of sum of detail coefficients provided in Table 4 also confirms the presence of high frequency transients. The observed THD is 6.77% and dominant harmonic components observed are 3rd, 6th and 10th harmonic components and provided in Table 5.

5.2. Sudden Load Connected to the Grid

The voltage signal of phase-A at bus 2 with suddenly load L-3 connected on bus B-3 and squared wavelet coefficients up to level 4 and approximation coefficient at level 4 are shown in Figure 5.

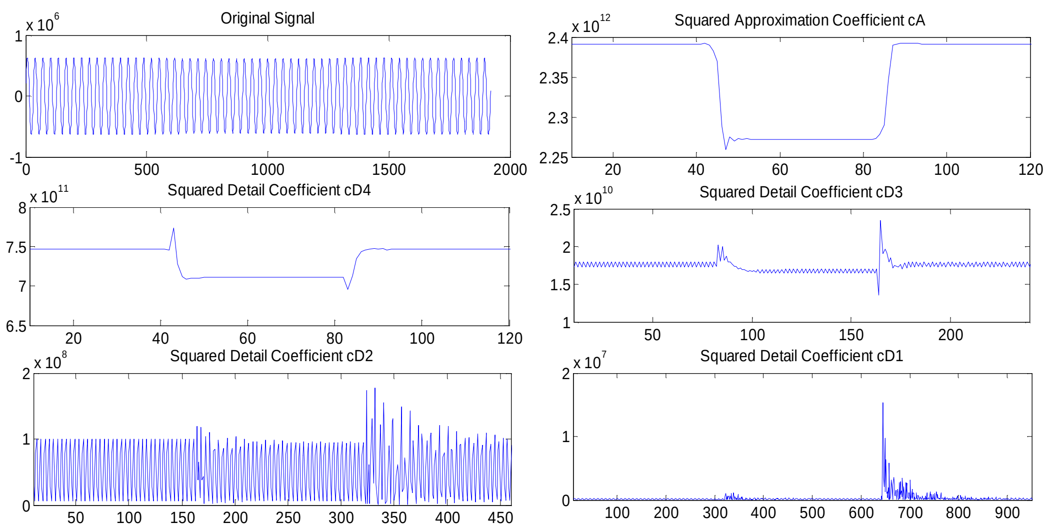

Figure 5: Squared Wavelet Coefficient of Voltage Signal of Phase-a Using Db4 as Mother Wavelet with Sudden Connection of Load with Grid

The sudden load connected to the test grid is detected at level 4 with high value of squared wavelet detail coefficient. The detection is also observed at level 3. The sudden connection of load produces voltage sag in the system which is detected in the detail at level 3 and 4 as well as approximation at level 4. Harmonic transients are detected by the details at level 1 and 2. High value of sum of detail coefficients provided in Table 4 also confirms the presence of high frequency transients. The observed THD is 7.72% and dominant harmonic components observed are 2nd, 3rd, 4th, 6th and 10th harmonic components and provided in Table 5.

5.3. Islanding of Test Grid from Utility Grid

The voltage signal of phase-A at bus 2 with outage of utility grid from test grid and squared wavelet coefficients up to level 4 and approximation coefficient at level 4 are shown in Figure 6.

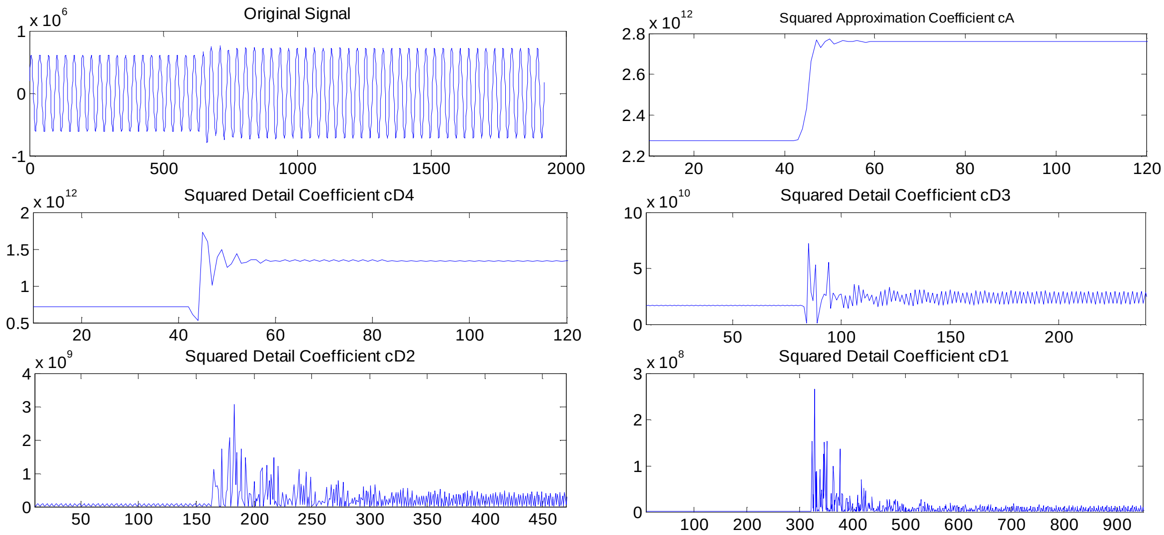

Figure 6: Squared Wavelet Coefficient of Voltage Signal of Phase-a Using Db4 as Mother Wavelet with Islanding of Test System from Utility Grid

The islanding of test grid from utility grid is detected at levels 1, 2 and 3 with high value of squared wavelet detail coefficients. The islanding of test grid from utility grid produces high voltage in the test system due to surplus power available. The connected load in the test grid is only 1010 MVA and generating station G-1 is generating power of 2100 MVA. While the test system is connected to the utility grid, the additional power generated will be injected into the utility grid behave as infinity source or sink for the test system. The presence of normal operating voltage with test grid connected to the utility grid and high voltage in islanding conditions are detected by the detail coefficients at level 4 and pproximation coefficients at level 4. Harmonic transients are detected by the details at level 1, 2 and 3. High value of sum of detail coefficients provided in Table 4 also confirms the presence of high frequency transients. The observed THD is 6.67% and dominant harmonic components observed are 3rd, 6th and 10th harmonic components and provided in Table 5.

5.4. Synchronization of Test System with Utility Grid

The voltage signal of phase-A at bus 2 with synchronization of test system with utility grid and squared wavelet coefficients up to level 4 and approximation coefficient at level 4 are shown in Figure 7.

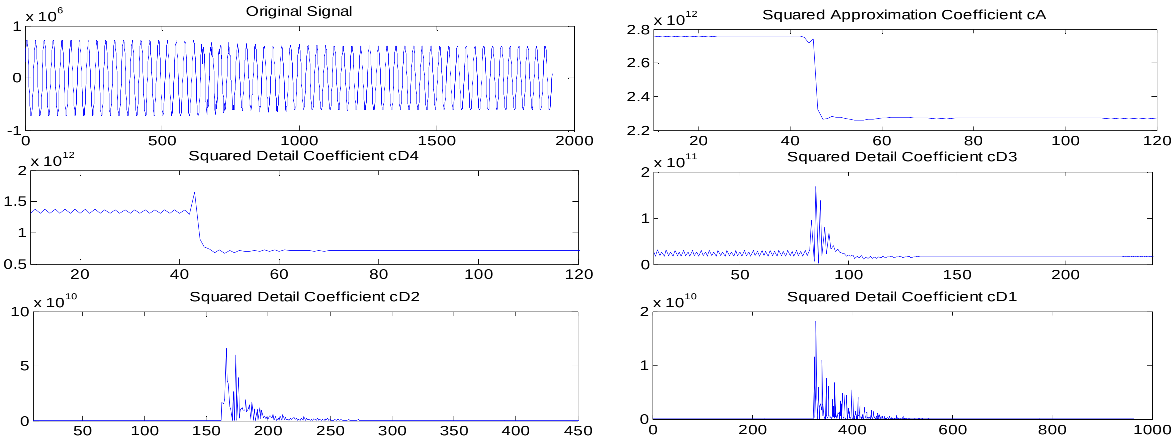

Figure 7: Squared Wavelet Coefficient of Voltage Signal of Phase-a Using Db4 as Mother Wavelet with Synchronization of Test System with Utility Grid

The synchronization of test grid with utility grid is detected at levels 1, 2 and 3 with high value of squared wavelet detail coefficients. The synchronization of test grid with utility grid reduces high voltage in the system due to surplus power available to the normal values by injecting surplus power available in the utility grid. The connected load in the test grid is only 1010 MVA and generating station G-1 is generating power of 2100 MVA. The presence of normal operating voltage with test grid connected to the utility grid and high voltage otherwise are detected by the detail coefficients at level 4 and approximation coefficients at level 4. Harmonic transients are detected by the details at level 1, 2 and 3. High value of sum of detail coefficients provided in Table 4 also confirms the presence of high frequency transients. The observed THD is 49.07% and all harmonic components from 2nd to 15th are dominant with values greater than 1% and provided in Table 5.

5.5. Three-Phase Fault

The voltage signal of phase-A at bus 2 with synchronization of test system with utility grid and squared wavelet coefficients up to level 4 and approximation coefficient at level 4 are shown in Figure 8.

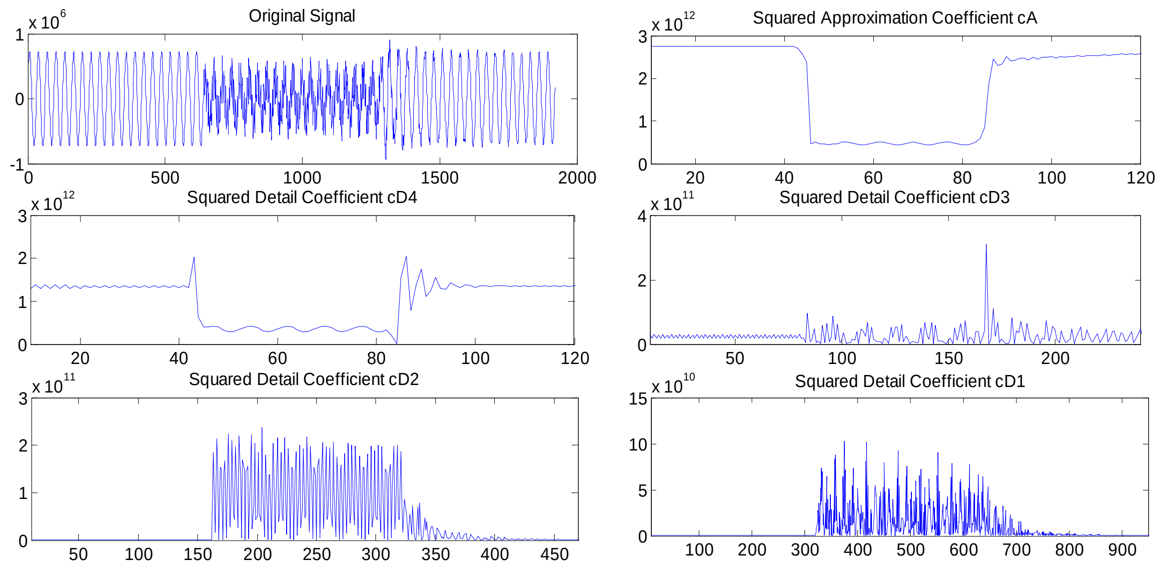

Figure 8: Squared Wavelet Coefficient of Voltage Signal of Phase-a Using Db4 as Mother Wavelet with Three-phase Fault at Bus-3

The inception of three-phase fault and fault clearance is detected at levels 1 and 2 with high value of squared wavelet detail coefficient present between the instants of fault inception and fault clearance. The three-phase fault produces voltage sag in the system which is detected in the detail at level 4 as well as approximation at level 4. Harmonic transients are detected by the details at level 1 and 2. High value of sum of detail coefficients provided in Table 4 also confirms the presence of high frequency transients. The observed THD is 27.56% and dominant harmonic components observed are DC offset and harmonic components from 2^{nd} to 15^{th} except 4^{th} are dominant with values greater than 1% and provided in Table 5.

Table 4: Sum of Absolute Values of Wavelet Coefficients

Type of Power System Operation	Wavelet Coefficients				
	Cd1	Cd2	Cd3	Cd4	Ca4
Load outage	3.9204e+5	3.7281e+6	3.2253e+7	1.0435e+8	1.9129e+8
Load connected to grid	3.9512e+5	3.7702e+6	3.2540e+7	1.0525e+8	1.9308e+8
Islanding of Test Grid from Utility Grid	1.5814e+6	6.0874e+6	3.5780e+7	1.2894e+8	2.0261e+8
Synchronization of Test Grid with Utility Grid	5.8958e+6	9.7863e+6	3.4690e+7	1.1611e+8	1.9833e+8
Three-phase fault	5.0655e+7	5.8733e+7	3.5222e+7	1.1861e+8	1.6906e+8

Table 5: The and Dominant Harmonic Components

Type of Power System Operation	Total Harmonic Distortion (%)	Dominant Harmonic Components
Load outage	6.77	h3, h6, h10
Load connected to grid	7.72	h2, h3, h4, h6, h10
Islanding of Test Grid from Utility Grid	6.77	h3, h6, h10
Synchronization of Test Grid with Utility Grid	49.07	h2, h3, h4, h5, h6, h7, h8, h9, h10, h11, h12, h13, h14, h15
Three-phase fault	27.56	DC, h2, h3, h5, h6, h7, h8, h9, h10, h11, h12, h13, h14, h15

6. CONCLUSIONS

In this paper, a new DWT based technique using SWTC for detection of disturbances in the utility network due to power system operations is presented. The proposed model of the power system is simulated in the MATLAB/Simulink environment. The results show the relative severity of disturbances produced in the network due to power system operations. The synchronization of test system with utility grid adversely affects the network. The three-phase fault also produces high disturbances as well as deterioration of voltage signals. The sudden outage of load, sudden connection of load with the grid and islanding of test grid from the utility grid also produces harmonics but their contents are low and admissible. The proposed technique using SWTC effectively detects the disturbances during power system operations which further helps in power system planning and providing necessary protection technique. This technique may also be used for online detection of disturbances for providing reference to the protection systems.

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APPENDICES

Biographies

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Om Prakash Mahela was born in Sabalpura (Kuchaman City) in the Rajasthan state of India, on April 11, 1977. He studied at Govt. College of Engineering and Technology (CTAE), Udaipur, and received the electrical engineering degree from Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, India in 2002. He received M. Tech. (Power System) degree in 2013. Presently, he is pursuing PhD degree from Centre of Information and Communication Technologies, Indian Institute of Technology, Jodhpur, India.

From 2002 to 2004, he was Assistant Professor with the RIET, Jaipur. From 2002 to 2013, he was Junior Engineer-I and since 2013, he has been Assistant Engineer with the Rajasthan Rajya Vidhyut Prasaran Nigam Ltd., Jodhpur, India. His special fields of interest are Transmission and Distribution (T&D) grid operations, Power Electronics in Power System, Power Quality and Load Forecasting, Renewable energy sources. He is an author of 34 International Journals and Conference papers. He is a Graduate Student Member of IEEE. He is Member of IEEE Power & Energy Society. He is fellow member of IAEME. He is reviewer of IJEEER. Mr. Mahela is recipient of University Rank certificate from MPUAT, Udaipur, India, in 2002 and Gold Medal in 2013.