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Current Signature Analysis of Power System Using Wavelet Transform

V. K. Pandey
Associate Professor,
SBITM Betul, MP, India

Dr. S. K. Shrivastava
Director,
SBITM Betul, MP, India

Abstract — **Events in power system have peculiar signature in terms of transforms or features. Regular monitoring of current, voltage and power signatures reveal health of interconnected power system. This paper proposes Signature analysis of current for determination of health of power system. This method is popular for motors but rarely cited for power system due to variability of connection and no unified approach. In this research work classification of sample power system using various signatures is investigated which will help us to know events of power system in a better way. Automation of power system fault identification using information conveyed by the wavelet analysis of power system transients is proposed. The work presented in this paper is focused on identification of simple power system faults. Aim of this proposed work is to exhaustively collect the signatures of power system events, which will help in analyzing the causes of unknown erratic performance or deviation of power system behavior. Results obtained are good estimate for selective discrimination between power system events due to wavelet features.**

Keywords — **CSA (current Signature Analysis), DWT (Discrete Wavelet Transform), CWT (Continuous Wavelet Transform).**

I. Introduction

Traditional CSA (Current Signature Analysis) measurements can result in false alarms and/or misdiagnosis of healthy systems due to the presence of current frequency components in the signals received. Theoretical advancements have now made it possible to predict many of these components, thus making CSA (Current Signature Analysis) testing a much more robust and less error prone technology.

The operators of electrical systems are under continual pressure to reduce maintenance costs and prevent unscheduled outages that can result in lost continuity, blackouts and reliability. The application of condition based maintenance strategies rely on specialized monitors to reliably provide a measure of the health of the system.

Thus, unexpected failures and consequent downtime may be avoided and/or the time between planned shutdowns for planned maintenance may be increased. Maintenance and operational costs are thus reduced. During the past twenty years, there has been a substantial amount of fundamental research into the creation of condition monitoring and diagnostic techniques for power system.

Diagnostic technologies have become even more prevalent through the 1990's and into the new century. Wavelet tools are used in different applications from image processing, signal processing, noise removal, detection and location of faults in power system.

In recent years, researchers have developed powerful wavelet techniques for the multi-scale representation and analysis of signals. Wavelets localize the information in the time-frequency plane. One of the areas where these properties have been applied is power engineering. Due to the wide variety of signals and problems encountered in power engineering, there are various applications of wavelet transform. Another important aspect of power disturbance signals is the fact that the information of interest is often a combination of features that are well localized temporally or spatially such as power system transients. This requires the use of analysis methods sufficiently, which are versatile to handle signals in terms of their time-frequency localization. The power system transients caused by disturbances have vital information embedded.

The main advantage of WT over STFT (Short Time-Fourier Transform) is that the size of analysis window varies in proportion to the frequency. Fourier techniques cannot simultaneously achieve good localization in both time and frequency for a signal. Most power signals of interest include a combination of impulse-like events such as spikes and transients for which STFT and other conventional time-frequency methods are much less suited for analysis.

WT can hence offer a better compromise in terms of localization. The wavelet transform decomposes transients into a series of wavelet components, each of which corresponds to a time domain signal that covers a specific octave frequency band containing more detailed information. Such wavelet components appear to be useful for detecting, localizing, and classifying the sources of transients. Hence, the wavelet transform is feasible and practical for analyzing power system transients.

II. Power System Transients

Health of Power System depends on at least a dozen key features of the electrical supply including frequency and voltage variations, but the most critical factor is waveform distortion or harmonic content. Harmonic voltages can cause malfunctions in sensitive equipment, such as the sensing circuits of circuit breakers and UPS switches, while harmonic current can result in overheating of conductors, transformers, motors coils and capacitors. These are potentially disastrous and cases of building supply failure and supply related fires are increasing.

Switching transient phenomena produce in Power Systems over-voltages, over-currents and electrical fields, which haven't to neglect.

Over-voltages are one the most significant problems in the power distribution system. Lightning over-voltages are

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one of the most probable over-voltages that are caused due to the direct strike of the lightning to the overhead contact system. Switching over-voltages due to the switching phenomena in the substations are also another major source of overvoltage generation in these systems. These over-voltages can be dangerous for the electrical equipment of the power system if not controlled and reduced effectively. Faults, energisation, auto-reclosure, power swings and many more is endless list of disturbance or transients in power system each with peculiar feature in terms of time or frequency.

III. Analysis of Transients by Wavelet Transform

Sixty years ago, a group of physicists studying the details of Brownian motion found out that a set of Harr functions (to be classed as wavelets later on) yielded a better result than the Fourier analysis. After this, Wavelets remained a mathematical curiosity until Grossman and Morlet introduced them in quantum physics in the 1960s. Serious applications in engineering were not considered until the 1980s when Stephan Mallat [1] discovered some important relationships between filter banks and the Wavelet Transform. This work, along with the work of Y. Meyer,[2] and Ingrid Daubechies [3] have become the basis for all engineering applications. It was not until a couple of years ago that researchers such as J. T. Heydt and A. W. Galli [5], Ribiero [6], and D. Robertson [7] introduced wavelets to power systems.

One common goal for all of these researchers [8-13] is to find a better tool to analyze power system transients and their effects on power systems. The ever increasing presence of solid state power loads on the power system grid, such as FACTS, SVCs, DC ties, and rectifier loads causes not only steady state harmonic distortion but significant non-stationary harmonic distortion. The efficient storage of the waveforms resulting from the transients, the identification of these transients, as well as the analysis of the transients propagation are critical areas where wavelet analysis has a great potential. M. Kezunovic & Z. Galijasevic [14], has worked on new software framework for automated analysis of power system transients. Tongxin Zheng, Makram, E.B., Girgis, A.A. [15] emphasized harmonic studies using wavelet transform. Gu, Y.H., Bollen, M.H.J. [16] experimented time-frequency and time scale domain analysis of voltage disturbances. Shyh-Jier Huang, Cheng-Tao Hsieh [17] details application of continuous wavelet transform for study of voltage flicker generated signals. Hong-Tzer Yang, Chiung-Chou Liao [18] proposed de-noising scheme for enhancing wavelet based power quality monitoring system. Angrisani L., Daponte P., D'Apuzzo M., Testa A. [19] suggested measurement method based on the wavelet transform for power quality analysis. Shyh-Jier Huang, Cheng-Tao Hsieh, Ching-Lien Huang [20] discussed Morlet wavelets to supervise power system disturbances". Power quality and signal processing were also investigated [21-24]. Wavelet and Neural combined were analysed by [25].

A. Continuous Wavelet Transform

Consider a time series, X_n, with equal time spacing Δt and n=0 …. N-1. Considering a wavelet function, Ψ_0 (η) that depends on a nondimensional time parameter η. This function must have zero mean and be localized in both time and frequency domain. The wavelets are generated from a single basic wavelet Ψ(t), namely, mother wavelet, by scaling and translation:

$$\Psi_{(s,\tau)}(t)=\frac{1}{\sqrt{s}}\Psi\left(\frac{t-\tau}{s}\right) \quad (1)$$

In (1) *s* is the scale factor, τ is the translation factor and the factor $s^{-1/2}$ is for energy normalization across the different Scales.

B. Discrete Wavelet Transform (DWT)

To obtain the DWT, the parameters a and b need to discretized. Discretizing a=2^j and b=2^jk will yield orthonormal basis functions for certain choices of Ψ.

$$\Psi_{(j,k)}(t)= 2^{-j/2}\Psi\,(2^{-j}j-k) \quad (2)$$

Mallat [1] showed that Multi Resolution Analysis (MRA) can be used to obtain the DWT of a discrete signal by applying low pass and highpass filters, iteratively, and subsequently down sampling them by two. Fig. 1 illustrates this process, where g[n] and h[n] are the highpass and lowpass filters, respectively. At each level, this procedure computes,

$$y_{high}[k]=\sum_n x[n].\,g[2k-n] \quad (3)$$

$$y_{low}[k]=\sum_n x[n].\,h[2k-n] \quad (4)$$

with N being the total number of samples in x[n] and *high y* and *low y* are the outputs of highpass and lowpass filters, respectively, at each level. The number of levels this process is repeated depends on the choice of the user. At the last level, the *y* [*k*] *low* obtained is called as Approximation.

The *y* [*k*] *high* computed at each level is called as the detail coefficient at that level. Current obtained at the generating station, plotted against time, is the transient source signal, X(n), considered in this paper.

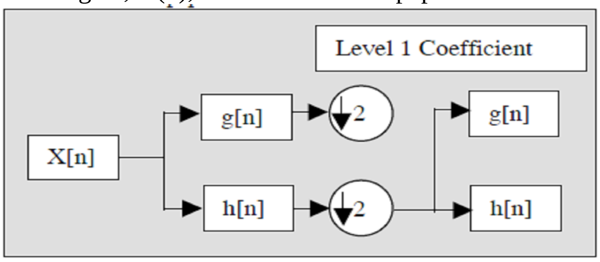

Fig.1. Computation of DWT by MRA

Power system transients are often of a broadband nature. For example, an SVC may cause, upon switching, frequencies around a kHz that superimpose on the 50 Hz fundamental. In order to accurately identify this transient, we could look at the spectrum of the data record. An accurate spectrum needs to resolve both the 50 Hz and the high frequencies. The discussion that follows shows why

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this a difficult task for a Fourier analysis but readily feasible in terms of the Wavelet Transform.

One of the most restrictive factors that come with any useful application of the Fourier Transform is the periodicity condition that the input function or the data record has to assume. In fact, if the input function is not periodic, we need the infinite past history as well as the infinite future history to determine the spectral information of the input function using the Fourier Transform**. A** way around this is to assume periodicity for the length of the data record. The result is an increase in the sidebands of the frequencies of interest because the: input function or data record becomes the unintended product of a square window function and the input data record. In order to limit the increase of the sidebands, windowing techniques, such as Hamming, Hanning, and the Short Time Fourier Transform (Gibbons Transform) were developed. This resulted in an improvement for the frequency of interest but not for all the frequencies present in, for example, a broadband signal. **A** broadband signal requires a window that is long for low frequencies and short for high frequencies. This is exactly what the Wavelet Transform provides. If the mother wavelet is chosen appropriately, the low frequencies are analyzed with wavelets that are dilated in shape, and the high frequencies are analyzed using, wavelets that are compressed in shape.

IV. System Study and Results

A simple power system network, shown in Fig.4 consisting of a generator 13.8 kV, 100 MW, a local load of 10 MW and remote load of 80 MW along with 10 km and 90 km line sections along with 13.8 kV/ 400 kV step up and step down transformer was used for the simulation purpose.

The transient disturbance generated due to fault is decomposed by wavelet transform into several detail coefficients and Approximations. The decomposition of the signal into these detail coefficients and approximations are carried out until the fundamental frequency signal (50Hz) is obtained as the approximation at that level. The detail coefficient obtained at the final level is characteristic for each type of simple power system fault.

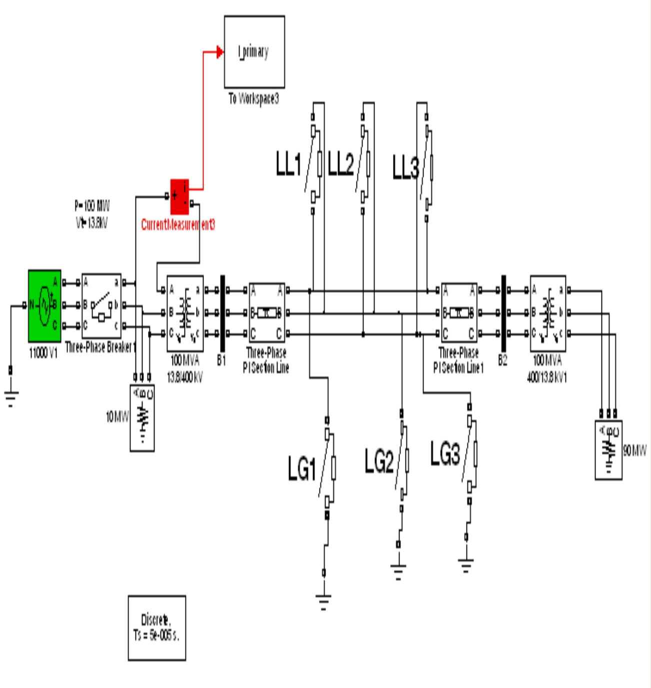

Fig.2. A simple power system Matlab Simulink Simpowersystem Model considered for analysis

Faults were created at a distance of 10kms from both the buses. Different types of faults were simulated using MATLAB package. Different types of faults were created and the transients were recorded for analysis. Simulation is carried out for eleven types of Faults i.e. AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, ABCG, ABC. Only SIGNATURE of Phase-A current was tracked and its wavelet coefficients along with energy were computed. The tabulated Results and Graph are as Follows

Table: Wavelet energy for different types of Faults

Wavelet Energy for Different Switching Instants					
t=0+	**t=+ve Peak**	**t=0-**	**t=-ve Peak**	**t=0+**	**Type of Fault**
967	**1033**	**913**	**1026**	**961**	**LG1**
524	**605**	**525**	**596**	**518**	**LG2**
523	**602**	**522**	**592**	**516**	**LG3**
901	**957**	**838**	**959**	**895**	**LL1**
523	**603**	**525**	**595**	**516**	**LL2**
785	**852**	**752**	**848**	**779**	**LL3**
999	**1064**	**931**	**1056**	**993**	**LLG1**
522	**603**	**523**	**594**	**515**	**LLG2**
936	**1002**	**883**	**994**	**930**	**LLG3**
1109	**1165**	**1017**	**1161**	**1103**	**LLLG**
970	**1037**	**904**	**1026**	**965**	**LLL**

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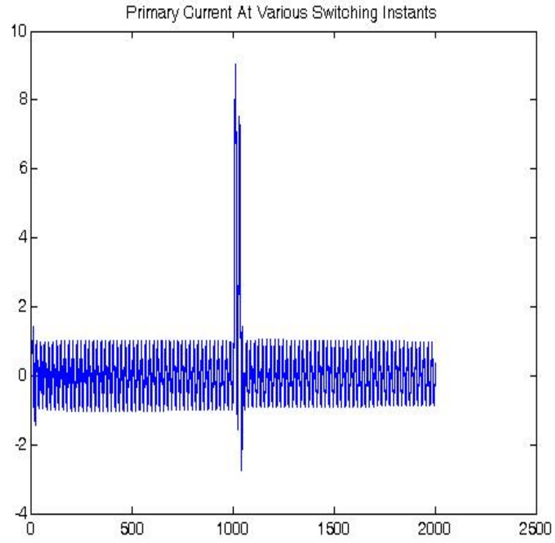
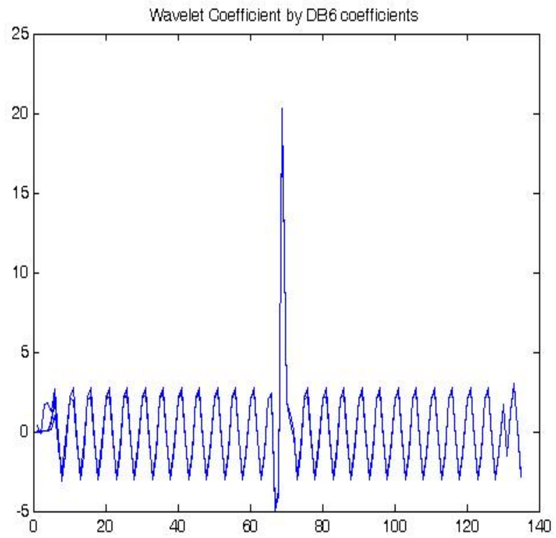
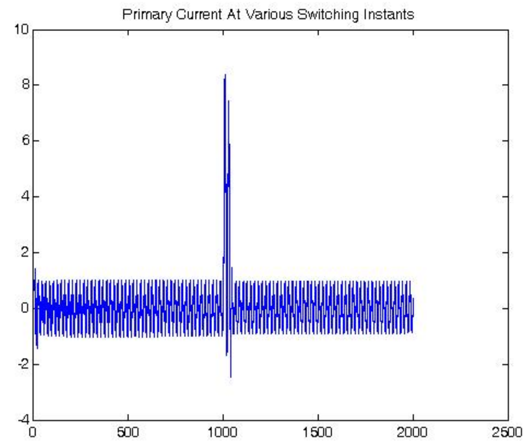
AG Fault



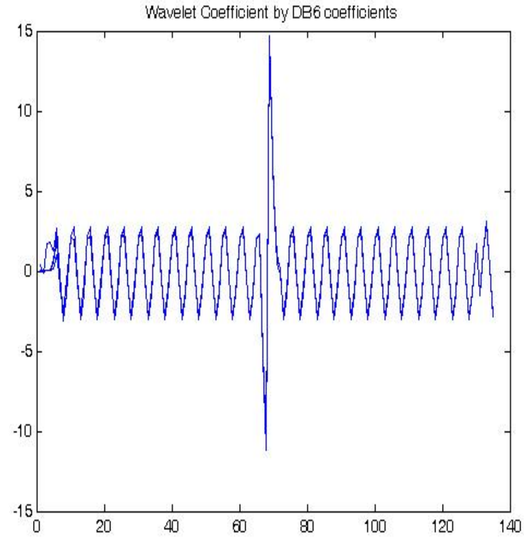
AG Fault Feature



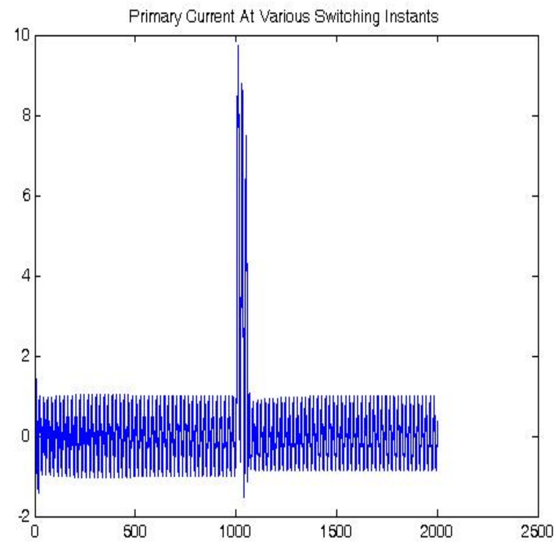
AB Fault



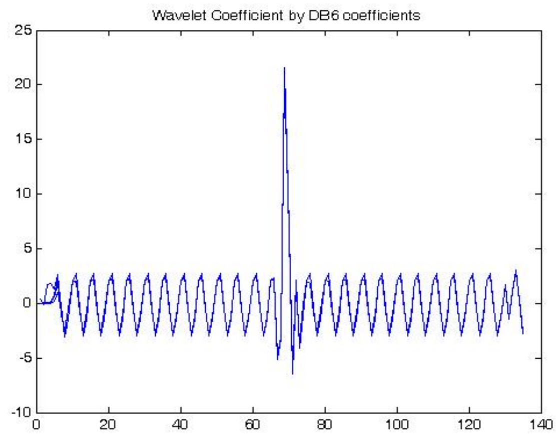
AB Fault Feature



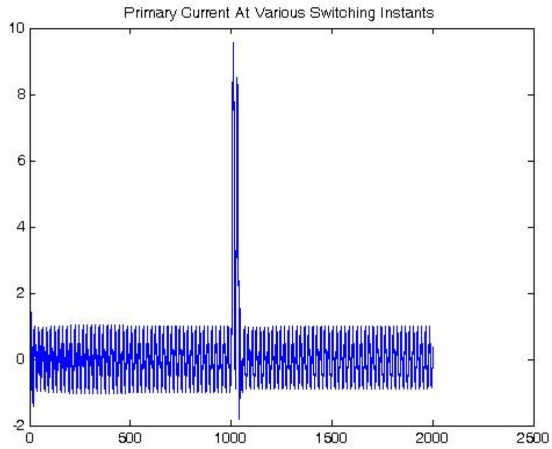
ABCG Fault



ABCG Fault Feature



ABC Fault



ABC Fault Feature

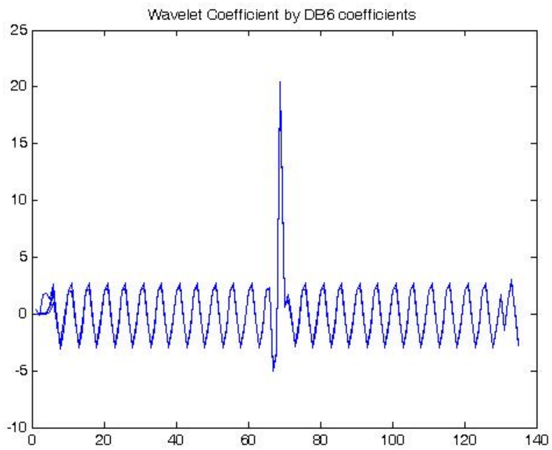


Fig.3. Different Fault Current Waveforms and their Wavelet [Detail Coefficients] Signature

These results show sudden change in the values of detail coefficients at the time of fault or disturbance and the severity by their peak value as well. Wavelet have strong discriminative power for different disturbances or faults. This is evident from collected signatures. The timing and severity helps in diagnosing the fault type. In case of similar coefficients for different fault events, work is extended to multi level feature extraction as well. A single methodology of all possible signature is sufficient to widely cover transient, dynamic performance of various current situations. Switching surges and lightning surges also can be selectively discriminated by this method.

Due to lack of "time" related information in other feature extraction transforms, wavelet has sufficiently proven to be the best for the instant of disturbance till date. Hence comparison with other transform or feature extraction will not reveal the full information. Certainly as a progress we will be highlighting the same in future work over this.

V. Conclusion and Future Scope

The application of wavelet transform to determine the power system signature is investigated here. Lot of low frequency and high frequency content of current signals reveals classification or say discrimination between different types of disturbances. In the past ten years, wavelet theory and applications have made great strides in fields outside the power engineering area, such as signal and image processing. It is only in the past couple years that wavelet analysis has been introduced for power system transients. The effort in this area has been very recent and seems to be moving in two main directions. One is concerned with the accurate identification and classification of transients. The other is more concerned with the development of an analysis tool to study the effects of transients on power system.

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AUTHORS PROFILE

Prof. V. K. Pandey
is working as Associate Professor in Shri Balaji institute of Technology and management, betul. He has authored and revised many prestigious textbooks. His areas of interest includes power systems, reliability analysis and fuzzy wavelet controller.

Dr. S. K. Shrivastava
is currently working as a Director in Shri Balaji institute of Technology and management, Betul. He is approved guide for Phd in various universities. He has total 29 years of teaching experience. He is a member of various professional bodies. He has number of international and national journal publication.