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A NOVEL CLARKE WAVELET TRANSFORM METHOD TO CLASSIFY POWER SYSTEM DISTURBANCES

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Abstract- With wide spread use of sensitive nonlinear electronic devices the switching transients are capable of degrading the quality of power. Utilities often switch the shunt capacitor banks to cope up with sagging voltage levels, thereby generating transients, which travel into the network of end users. Capacitor switching can cause over voltage, resonance and in advert tripping of Adjustable Speed Drives (ASD) and many other sensitive electronics devices. This paper presents a method to distinguish between transients arising out of capacitor switching, , load switching and line to ground fault. The three phase voltages are first transformed to alpha, beta, and zero sequence components using Clarke transform. The DWT of the alpha, beta, and zero sequence components is obtained and the magnitude of the detail coefficients is used to extract distinguishing features. A real power system has been simulated in PSCAD/EMTDC with lines modelled using frequency dependant phase model

Keywords: Transients, Clarke Transform, Discrete Wavelet Transform (DWT), Multi Resolution Analysis, Power Quality.

I. INTRODUCTION

In power system the term transient denotes those phenomenons in voltage and current with a short duration. Traditionally, the interest in power system transients has been related to the correct operation of circuit breaker, and to over voltages due to switching of HV lines. But now a day, transients are seen as a potential power quality problem. Hence transient waveforms are needed to be characterized and analyzed. Methods have to be developed to extract information on the cause of transient waveforms.

Power Quality studies have become an important subject due to wide spread use of sensitive electronic equipments. Moreover the deregulated power sector has enhanced the competition amongst various power producers leading to a need to improve the quality of electric supply. The cause of degradation of power quality must be investigated to improve the quality. The wide uses of accurate electronics devices require extremely high quality supply. Even developed economics of the world are losing billions of dollars to power quality problem. Hence the research of power quality issues is increasing exponentially in the power engineering community in the past decade.

Ibrahim et al provided an excellent survey of the expert systems, artificial intelligence technique for power quality in [1], which includes Fuzzy logic, artificial neural network, and Genetic algorithm. Gouda et al proposed an effective wavelet Multi resolution analysis method for analyzing power quality transient events based on standard deviation and rms value, in [2] and [3]. Huang et al proposed an arithmetic coding approach based on wavelet packet transform to compress power quality disturbance data in [4]. Wavelet based on line disturbance detection for power quality applications are discussed in [5], giving faster and more accurate discrimination between the transient events compared to conventional methods. T. E Grebe presents power quality issues arising out of application of utility capacitor banks, such as capacitor switching transients and power system harmonics in [6].

Santose et al. extracted the features of power quality signals in terms of wavelet coefficients using the multi resolution analysis as inputs to the neural network for identifying impulses, voltage sags and transient oscillations in [7]. Perunicic et al. in [8] used the wavelet coefficients of DWT as inputs of self organizing mapping neural network to identify dc bias, harmonics, voltage sags, and other transient disturbances. Elmitwally et al. employed the preprocessed wavelet coefficients as inputs to the neuro-fuzzy systems for classifying the voltage swell, voltage sag, interruption, impulse, voltage flicker, harmonic, and flat topped wave [9]. Angrisani et al proposed an approach for estimating the magnitudes and durations of the disturbances using the continuous wavelet transform and used these two features for identifying voltage sag, in [10].

In [11], Ying et al. described the use of DWT to extract the distinguishing features which are fed to hybrid self organizing mapping neural network for classification. They have distinguished between capacitor switching and load switching only. However in this paper we propose a method to distinguish between capacitor switching, load switching and line to ground fault, that too, without using artificial neural networks. In all the references mentioned above, rigorous preprocessing and/or post processing of the signal generated by the disturbance is essential to extract the distinguishing features, which is not required in our proposed method, as the signal is transformed twice, first by using Clarke transform and then wavelet transform.

Although a lot of research has been reported the technique of finding the cause of a particular disturbance leading to power quality issue is still both difficult and challenging. Motivated by the research in the area of intelligent system and wavelet analysis this paper aims to propose an effective classification method for some power quality disturbances based on Clarke and wavelet transform.

Wavelet analysis is capable of revealing features of data that other analysis could miss including trends, breakdown points, discontinuities and self similarity. Wavelet transform have attracted interest for capturing and analyzing power system transients. It is necessary to identify the disturbance that resulted in transient. New powerful tools for the analysis and classification of power quality disturbances are currently available and the automatic classification of power quality disturbance has made tremendous progress thus far. However since correct classification rate for the actual events is not as high as classification methods used in areas such as pattern recognition, speech recognition and so on, there is still room for improvement.

In this paper a novel Clarke-wavelet transform based technique is presented to identify the frequently occurring disturbances in the power system by analyzing the transients produced by these events. It is observed that capacitor switching, load switching and line to ground fault are frequently occurring events/disturbances in the power system giving rise to transients. Hence this paper aims to classify these events using Clarke-wavelet transform approach. In the proposed method the three phase voltages are first transformed to alpha, beta, and zero sequence components using Clarke transform. The DWT of the alpha, beta, and zero sequence components is obtained to extract distinguishing features.

The selection of mother wavelet is a formidable task. A wavelet suitable for a particular application may be unsuitable for another. The wavelet which best matches the shape of transient to analyze is usually the most suitable one. Although wavelet transform is quite good in analyzing power system transients direct use of it does not guarantee the extraction of relevant features.

Hence Clarke transform is used prior to the application of DWT. This paper is organized as follows. Discrete wavelet transform is discussed in section II. The Clarke-wavelet transform based feature extraction method is explained in section III. Simulation and results are given in section IV. Finally, the conclusion is presented in section V.

II. DISCRETE WAVELET TRANSFORM

Wavelet is a powerful time frequency method to analyze a signal within different frequency ranges by means of dilating and translating a single function called mother wavelet. Formulation of DWT is related to filter bank theory. It divides the frequency band of input signal into high and low frequency components by using high pass $h(k)$ and low pass $g(k)$ filters. This operation may be repeated recursively, feeding the down sampled low pass filter output into another identical filter pair, decomposing the signal into approximation $c(k)$ and detail coefficients $d(k)$ for various resolution scales. In this way, DWT may be computed through a filter bank framework, in each scale, $h(k)$ and $g(k)$ filter the input signal of this scale, giving new approximation and detailed coefficients respectively. The filter bank framework is shown in Figure 1.

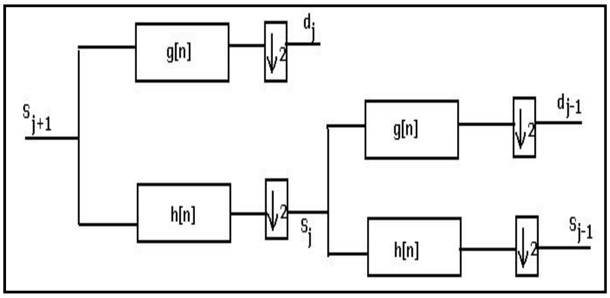

Figure 1. Two band Multi-resolution analysis of Signal

The down pointing arrow denotes decimation by two and boxes denote convolution by $h(k)$ or $g(k)$. The coefficients of filter pair are associated with the selected mother wavelet. Daubechies wavelet family is mostly used for analysis of power system transients.

III. FEATURE EXTRACTION TECHNIQUE

The classification of disturbance is not straight forward by using only DWT decomposition of the phase voltages. Hence the three phase voltages are first operated upon by the Clarke transform to generate the alpha component, beta component and zero sequence component. These transformed components contain the information pertaining to the relevant disturbance. The features specific to a particular disturbance are then extracted by decomposing the alpha component, beta component and zero sequence component using DWT. The magnitude of the detail coefficients of the decomposed components is observed to classify the event.

The Clarke transform relates the phase voltages and component voltages through the following matrix expression:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} V_\alpha \\ V\beta \\ V_0 \end{bmatrix}$$

The alpha component, beta component and zero sequence components are then decomposed up to fifth level using db4 (Daubechies 4) as the mother wavelet.

IV. SIMULATIONS AND RESULTS

The simplified real power system shown in Figure 2 is simulated in PSCAD /EMTDC to test the applicability of the proposed method. The three phase voltages are monitored at buses 5, 3, and 2 of utility. The lines have been constructed by using frequency dependant phase model in PSCAD /EMTDC. The system details are given in the appendix.

The following switching cases at bus 5 have been presented

i. Isolated capacitor switching:

a) Only 15 MVAR capacitor switched ON

b) Only 10 MVAR capacitor switched ON

ii. Back to Back capacitor switching:

a) 15 MVAR capacitor in the circuit and 10 MVAR capacitor switched ON

b) 10 MVAR capacitor in the circuit and 15 MVAR capacitor switched ON

iii. Load switching done from 30 MW to 80 MW

iv. Line to ground faults for various load conditions

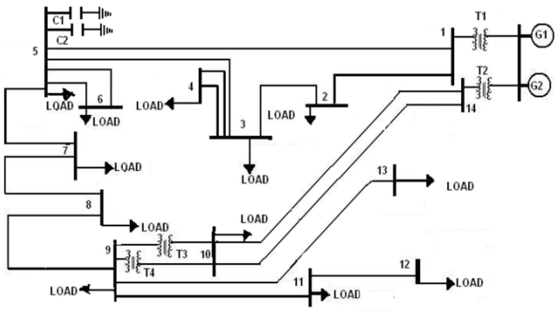

Figure 2. Single line diagram of the simplified power system

The sampling frequency is 20 KHz. The DWT decomposition is obtained up to 5th level. The level and its frequency band coverage are given in Table 1. The alpha component (blue), beta (green) component and zero (red) sequence components obtained using the Clarke transformation corresponding to the four types of switching/fault are shown in Figure 3. The quantity on the horizontal axis is time in seconds. Only, the line to ground fault waveform is different than the other three waveforms. Isolated capacitor switching, back to back capacitor switching and load switching waveforms have the same pattern. However the distinguishing features are explicitly observed in the DWT decomposed waveforms of the alpha component, beta component and zero sequence component.

The DWT detail level coefficients from d1 to d5, of the decomposed alpha component, beta component and zero sequence components, for same instant, of isolated capacitor switching, back-to-back capacitor switching, load switching and line to ground fault are shown in Figures 4, 5, 6 and 7, respectively. The quantity on the horizontal axis is time in seconds.

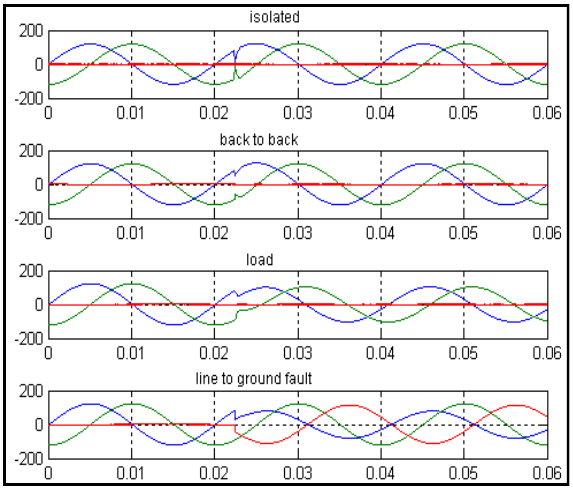

Figure 3. Alpha, beta and zero sequence components of the phase voltages

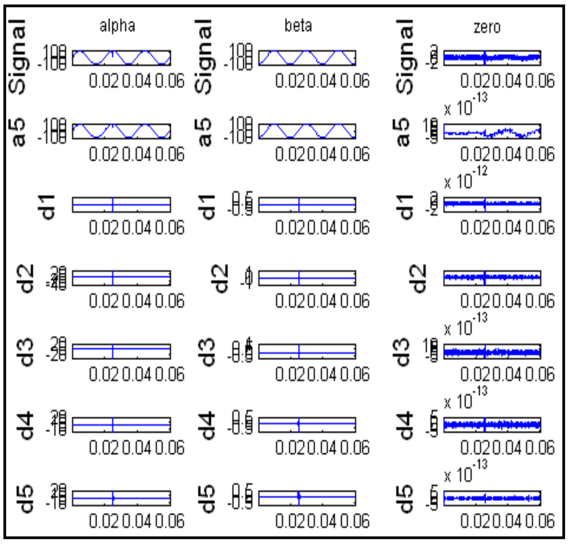

Figure 4. Wavelet decomposition of isolated capacitor switching transient

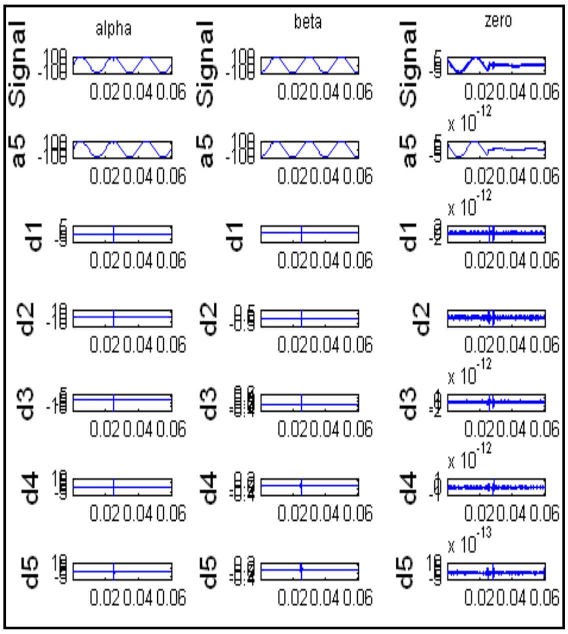

Figure 5. Wavelet decomposition of back to back capacitor switching transient

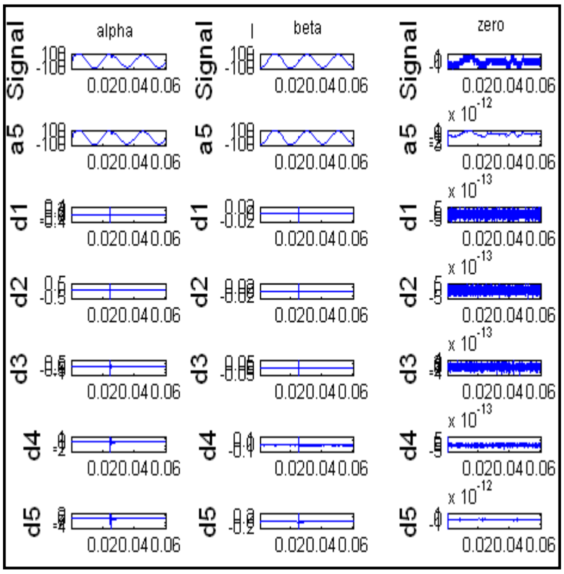

Figure 6. Wavelet decomposition of load switching transient

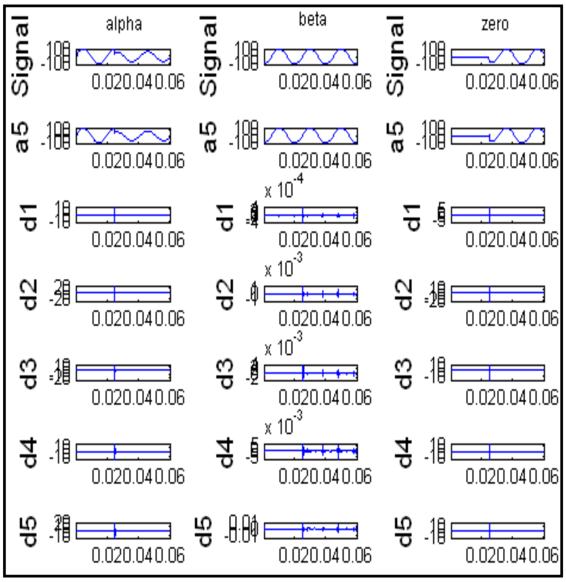

Figure 7. Wavelet decomposition of line to ground fault transient

It is observed that detail coefficients of the zero sequence components are zero (note the extremely small magnitude of the order of 10^{-12} and $10^{-13)}$ for isolated capacitor switching, back-to-back capacitor switching, load switching, thereby separating these three events from line to ground fault. Moreover load switching can be segregated from isolated capacitor switching and back to back capacitor switching on the basis of magnitude of the detail level one, d1, coefficients of the alpha component. The magnitude of these coefficients is less than one for load switching but very high for capacitor switching. Therefore, capacitor switching, load switching and line to ground fault can be classified from these criterion. However, discrimination between isolated capacitor switching and back to back capacitor switching is not possible with this technique. The flow chart for the detection and classification of the switching and fault is depicted in figure 8.During abnormal condition the magnitude of coefficients of first detail level exceeds 0.5.

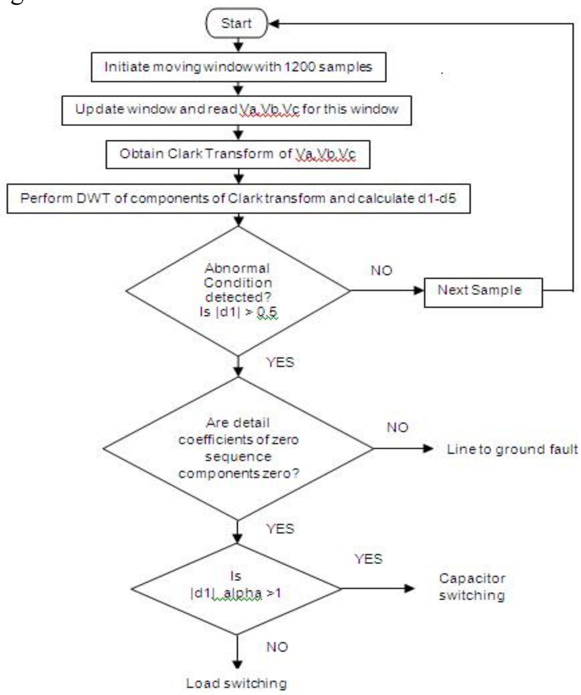

Figure 8. Flow chart for detection and classification

V. CONCLUSIONS

A novel and simple method based on Clarke-wavelet transform for classification of capacitor switching, load switching and line to ground fault has been proposed. The Clarke transform components, via alpha, beta and zero sequence, derived from the phase voltages are decomposed using DWT, to extract distinguishing features. The validity of this method is tested successfully by simulating the switching/fault events on a real power system modelled in PSCAD/EMTDC.

APPENDIX

Generator Data

G_1 and G_2 are identical machines: 294.1 MVA, 16.5 kV, 50 Hz
Stored energy constant: H=1.08 kW-sec/kVA,
X_d=1.83, X'_d=0.239, X''_d=0.187, T'_{do}= 8.15 sec,
T''_{do}=0.04 sec, X_q=1.74, X''_q=0.205, T''_{qo}=0.15 sec,
R_a=0.00104 ohm, X_P=0.241.All reactances are in p.u.

Transformer Data

T_1: 75 MVA, 132/16.5 kV, Y/Y, X=0.115 p.u.
T_2: 315 MVA, 230/16.5 kV, Y/Y, 50 Hz, X=0.125 p.u.
T_3: 200 MVA, 220/132 kV, Y/Y, X=0.138 p.u.
T_4: 100 MVA, 220/132 kV, Y/Y, X=0.987 p.u.

Line Data

132 kV Line

Z_1=0.1545+j0.387 Ω/km
Z_0=0.3025+j1.4096 Ω/km

220 kV Line

Z_1=0.08+j0.4 Ω/km
Z_0=0.27+j1.34 Ω/km

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BIOGRAPHIES

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