Discrimination of Capacitor Switching Transients Using Wavelet

M.A.Beg¹, Dr.M.K.Khedkar², Dr.G.M.Dhole³
¹,³Shri Sant Gajanan Maharaj College of Engineering, Shegaon
²Vice Chancellor, Sant Gadege Baba Amravati University.

Abstract: Switchable shunt capacitor banks are in extensive use to improve loading of the lines as well as to support system voltages. As these capacitor banks are frequently switched in and out of duty, energization and de-energization transients are produced and raise concern. These are the most common transient events present in power systems. This paper presents a method to distinguish between transients arising out of isolated capacitor switching and back-to-back capacitor switching. The DWT (Discrete Wavelet Transform) of modal voltage signal is used to extract distinguishing features from the voltage waveform of these events.

Keywords: Transients, Discrete Wavelet Transform (DWT), Multi Resolution Analysis (MRA), power quality (PQ).

I. INTRODUCTION

Due to their widespread applications, capacitor switching transients are the most common transient events on the power system, second only to voltage sag disturbances. Capacitor switching operations are frequently correlated with problems such as nuisance tripping of adjustable speed drives, process controls, and any load that cannot tolerate subcycle overvoltage transients. Unfortunately, most utilities have very limited resources to identify these problems and correlate them with the capacitor switching operations.

Switching of transmission capacitor banks may cause high phase to phase voltages on transformers and the magnification of transient at consumer end distribution capacitor. Problems are common in plants with capacitor and dc drive systems. The advent of pulse width-modulated (PWM) inverters created a whole new concern for capacitor switching

The application of shunt capacitors can lead to following additional side effects:

1) Bring about severe harmonic distortion, and resonance with load-generated harmonics;
2) Increase in the transient inrush current of power transformer in the system, create overvoltage, and prolong its decay rate;
3) Capacitor themselves can be stressed due to switching transient;
4) Increase the duty on switching devices, which may be stressed beyond the specified ratings in American National Standards Institute (ANSI)/IEEE standards;
5) Discharge into an external fault, and produce damaging over voltages across current transformer (CT) secondary terminals; and
6) Impact sensitive loads, i.e. drive system, and bring about the shut down.

The wavelet transform (WT) can be used to detect PQ problems and identify their occurrences in terms of time, generating data in both time and frequency domains, via the multi resolution analysis (MRA). These data will also be crucial to the classification of these events, as unique features of the various types of disturbance can be identified in the data emerging from the different levels of resolution, available in the MRA. The results obtained may be dealt with by a variety of techniques, including artificial neural networks (ANNs) in order to classify them.

Parsons [1] investigated the disturbance energy flow during the transient period and the polarity of the initial peak of the disturbance power to find out the relative but not the exact location of the switched capacitor bank. Sochuliaková [2] presented an analytical expression of the position of a switched capacitor as a function of transient frequency. Kim [3] applied a backward Kalman filter to find the location of a switched capacitor bank by estimating the voltage rise of capacitor bank. Unfortunately, this solution is also impractical to implement because it is based on the assumption that an exact power system dynamic model exists.

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,[4]. Makram et al in [5] described a frequency domain based approach for the analysis of shunt capacitor switching transients in the presence of harmonic sources, unbalanced feeder configuration, and combinations of single- and three-phase loads. Chang et al analyzed the effect of transients arising due to utility capacitor switching, on mass rapid transit(MRT), using
EMTP simulations considering size, location, and switching instant, in [6]. In this paper a single modal voltage signal is generated by combining all the three phase voltages. This modal signal is then decomposed using DWT up to five detail levels. The spectral energy density of the fifth detail level coefficients is used to discriminate between isolated and back to back capacitor switching events. This paper is organized as follows. Wavelet transform is briefly discussed in section I. Features for discrimination is presented in section II. Finally the conclusion is presented in section III.

II. WAVELET TRANSFORM AND MULTI RESOLUTION ANALYSIS

A wavelet is a short-term duration wave. These functions have been proposed in connection with the analysis of signals - primarily transients - in a wide range of applications. The basic concept of wavelet analysis is the use of a wavelet as a kernel function in integral transforms and in series expansions much like the sinusoid is used in Fourier analysis or the Walsh functions in Walsh analysis. Unlike Fourier analysis which uses one basis function, wavelet analysis relies on wavelets of a rather wide functional form. The basis wavelet is termed a *mother wavelet*. An informal statement of conditions for a function to be a wavelet are that the function:

- Must be oscillatory.
- Must decay quickly to zero (can only be non-zero for a short period of the wavelet function).
- Must integrate to zero (i.e., the dc frequency component is zero).

In most cases, a band pass type signal (limited in time and frequency) is admissible. These conditions allow the wavelet transform to translate a time-domain function into a representation that is localized in both time (space) and frequency (scale). The term *time-frequency* is used to describe this type of multi resolution analysis.

Wavelet transform expands a signal in terms of a wavelet, generated using translation and dilation of a fixed wavelet function called the “mother wavelet”. A mother wavelet is defined as

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

Wavelets analyze any signal by using an approach called the multi resolution analysis (MRA), i.e., it analyzes the signal at different frequencies with different resolutions. MRA is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at low frequencies. Discrete wavelet transform (DWT) can be implemented using a tree-structured filter bank. An input signal \( x[n] \) is decomposed as

\[ y_{\text{high}}[k] = \sum_n x[n] \cdot g[2k - n] \]  
\[ y_{\text{low}}[k] = \sum_n x[n] \cdot h[2k - n] \]

Where, \( y_{\text{high}}[k] \) and \( y_{\text{low}}[k] \) are the outputs of the high pass and low pass filter at a given level, after sub-sampling by 2. Here, \( g[n] \) is a high pass filter; \( h[n] \) is a low pass filter.

The selection of the mother wavelet depends on the application.

In this paper Daubeschies, with four filter coefficients (db4) has been used. db4 is very well suited to analyze power system transients.

III. FEATURE FOR DISCRIMINATION

An existing 132 kv transmission network of state transmission company has been simulated in PSCAD-EMTDC and analysis is done using wavelet tool box in MATLAB. A modal voltage signal-

\[ E_m = E_{abc} \]

Where \( E_{abc} = [E_a, E_b, E_c]^T \)

\( E_m \) is modal voltage signal, \( E_a, E_b, E_c \) are three phase voltages and \( M \) a column vector of modal coefficient having 1x3 dimensions, has been used in this method.

MRA of wavelet transform of modal signal provides the following information -

\[ A_n, d_1, d_2, ..., d_n = DWT(E_m) \]

Where, \( A_n \) is the set of approximate wavelet coefficients at level \( n \).

\( d_1, d_2, ..., d_n \) is the set of detailed coefficients of wavelet transform at first, second...\( n^{th} \) decomposition level. Fig.1 and 2 shows the MRA wavelet decomposition of modal voltage signal of (4) for isolated and back to back capacitor switching. The top figure is the modal voltage signal, \( a_n \) represent the approximate coefficients of the fifth level and \( d_1 \) to \( d_5 \) are the detail coefficients. Horizontal axis is time in seconds. Close examination of these provides no
distinguishing features between these events, except changes in magnitudes of coefficients. However, microscopic inspection of detailed level 5 coefficients provides some hope for distinguishing feature extraction.

Let ‘i’ be the level where possible discrimination is found (in this case fifth level) and corresponding wavelet coefficients are denoted by ‘d_i’.

The spectral energy density of d_i coefficients for level 5 can be calculated using

\[ S_{x_i}(n) = d_i^2(n) \]  
(6)

Let \( \mu_{A}(n) \) be the membership function given by

\[ \mu_{A}(n) = \frac{1}{1 + S_{x_i}(n)} \]  
(9)

\[ \mu_{\compliment}(n) = 1 - \mu_{A}(n) \]  
(9)

Therefore, the spectral energy density \( S_{x_i}(n) \) of d_i coefficients is mapped as follows-

\[ S_{x_i}(n) \rightarrow (0,1] \]  
(7)

using the following membership function-

\[ \mu_{A}(n) = \frac{1}{1 + S_{x_i}(n)} \]  
(8)

compliment of (8) can be obtained from (9)

Fig. 3 provides the comparative graph of spectral energy density for level 5 (i.e. d5) coefficients for these two cases. Variation of spectral energy density follows the same pattern for dominant coefficients up to certain duration of time, but difference is observed in transient decay time. Back to back capacitor switching transients decays faster than isolated case. Smaller magnitude oscillations are observed in isolated switching case (marked with rectangle in Fig.3) which is a distinct feature.

Equation (9) provides discrete sequence where low magnitude long duration transients acquire higher membership than the high magnitude transients. Hence, low magnitude long duration transients which are not easy to detect directly from the wavelet coefficients are clearly visible in mapped domain, and are shown in Fig. 4 marked with rectangles. Hence isolated capacitor switching can be discriminated from back to back capacitor switching.
Figure 3 Spectral energy density plot for isolated and back to back capacitor switching

Figure 4 Feature extraction

IV. Conclusion
Distinguishing feature for identification of isolated capacitor switching and back to back capacitor switching is extracted in this paper using wavelet analysis. Wavelet is capable of extracting low frequency as well high frequency components from the power system transients and hence it is superior to Fourier analysis.

REFERENCES: