

DISCRETE WAVELET TRANSFORM TECHNIQUE AND PROBABILISTIC NEURAL NETWORK APPLICATION IN RECOGNITION OF POWER CAPACITOR SWITCHINGS

NHẬN DẠNG CÁC HIỆN TƯỢNG QUÁ ĐỘ DO ĐÓNG CẮT TỤ BÙ BẰNG KỸ THUẬT WAVELETS VÀ MẠNG NƠ RÔN XÁC SUẤT

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ABSTRACT

With wide spread use of sensitive nonlinear electronic devices, electromagnetic transients are capable of degrading the quality of power. Utilities often switch the shunt capacitor banks to cope 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 transients arising out of isolated capacitor switching, back-to-back capacitor switching, prestrike capacitor switching, restrike capacitor switching and voltage magnification. The Discrete Wavelet Transform (DWT) of modal voltage signal is used to extract distinguishing features from the voltage waveform of these events. The detail coefficients for d1 and d5 level only, obtained from DWT are processed, mapped and given to Probabilistic Neural Network (PNN) network, which accordingly classify the events.

Keywords: Power System Transients; Multi-Resolution Analysis; Probabilistic Neural Network; Shunt Capacitor Switching; Power Quality Disturbances.

TÓM TẮT

Với ứng dụng rộng rãi các thiết bị điện tử có tính phi tuyến có độ nhạy với chất lượng điện áp cung cấp. Các quá độ điện áp ảnh hưởng chất lượng cung cấp điện. Các công ty điện lực thường sử dụng các bộ tụ bù để nâng cao điện áp, do đó sẽ tạo ra các quá độ điện từ ảnh hưởng điện áp khách hàng như đóng cắt 1 trạm tụ cách ly, đóng 2 trạm tụ song song, hiện tượng khuếch đại điện áp, phóng điện trước, phóng điện sau. Kỹ thuật khai triển Wavelets rời rạc (DWT) với phân tích đa giải Multi-Resolution Analysis (MRA) được thực hiện trong bài báo để phân tích và nhận dạng các hiện tượng quá độ điện từ trong hệ thống điện thông qua các giá trị năng lượng của các mức. Các kết quả nhận được trong bài báo cho thấy việc đánh giá các hiện tượng nhiễu trong hệ thống điện dùng kỹ thuật Wavelets cho phép nhận được nhiều thông tin định lượng và là cơ sở trong quá trình đánh giá chất lượng điện năng. Kỹ thuật mạng nơ ron xác suất sử dụng để nhận dạng tự động các sự cố do đóng cắt tụ bù gây ra.

Từ khóa: Quá độ hệ thống điện; Phân tích đa giải Wavelet; Mạng Nơ ron xác suất; Đóng cắt tụ bù; Nhiễu chất lượng điện năng.

1. INTRODUCTION

Diverse power disturbances are in existence in power systems: capacitor bank switching, voltage sag, voltage swell, interruption, flicker, harmonics, lightning impulse, fault due to short-circuit, inrush current on no-load transformer energization..., and power quality of the system may be greatly affected. Therefore, researches in the field of analysis, recognition, and classification of power disturbances in an effort to mitigate their negative impacts on power quality have drawn much interest by many authors in recent years [1–7]. For most of these research works, signal patterns such as pure sine wave, sag, swell, harmonics, flicker, capacitor switching, interruption... are created in Matlab package, then inputted to Matlab's Wavelets Toolbox for wavelets coefficients calculation. In [5], wavelets technique was used to extract information of interest from the obtained power disturbance signals, then the energy distribution by Parseval theorem calculated corresponding to various decomposition levels of a variety of disturbances was inputted to neural networks or neuro-fuzzy classifiers for recognition and classification purpose. In this paper, various practical power disturbances further to the previously mentioned phenomena, pertaining to capacitor bank switching in power grid, such as isolated capacitor bank switching, capacitor bank back-to-back switching, capacitor bank magnification, prestrike, and restrike, are analyzed in the well known transient phenomena analysis software ATP-EMTP (Alternative Transient Program). Simulated power disturbance results are then converted to Matlab-compatible format, then analyzed by Matlab Wavelets Toolbox with Discrete Wavelet Transform (DWT) by Daubanchie "db4" wavelet function. Energy distribution

of the distorted signals per Parseval's theorem was calculated and plotted in function of decomposition levels to extract interesting features. As a result of this analysis, important remarks and conclusions are made to recognize and classify different disturbances.

2. POWER QUALITY DISTURBANCES SIMULATION BY ATP-EMTP

Following are various power quality disturbances simulations performed with the help of ATP-EMTP.

2.1 Capacitor bank switching

Simulations were made with various switching phenomena of a power capacitor bank into a grid.

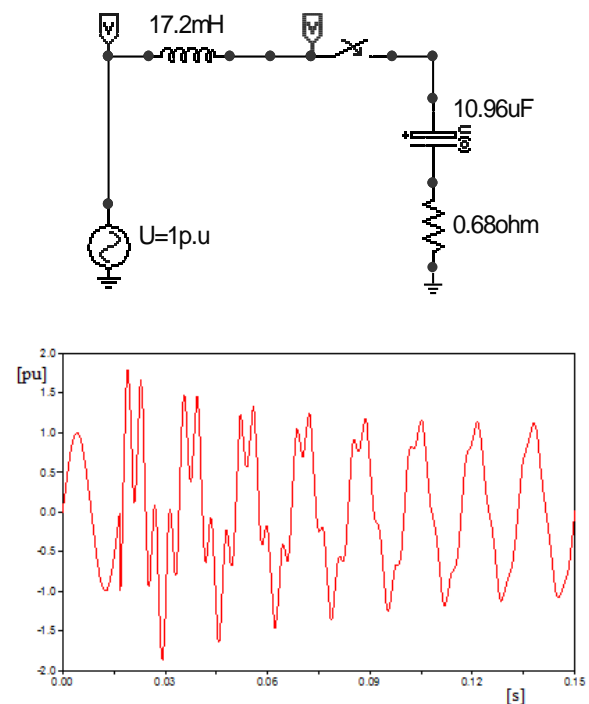


Figure 1. Simulation circuit & Voltage wave

Overvoltages depend heavily on switching timing and a value of 1.89 pu may be reached when closing to capacitor bank with power wave in the maximal peak.

2.2 Voltage magnification

A bank of 20 MVAR is closed onto the primary side of 110/22 kV transformer of 10

MVA, $X = 0.1$ pu, with a capacitor bank of 2 MVAR on the secondary side. A potential side effect of adding power factor correction capacitors at the customer location is that they may increase the impact of utility capacitor switching transient on end-user equipment, magnification voltage occurs when $L_1 \times C_1 = L_2 \times C_2$ and current magnification value amplitude is very high.

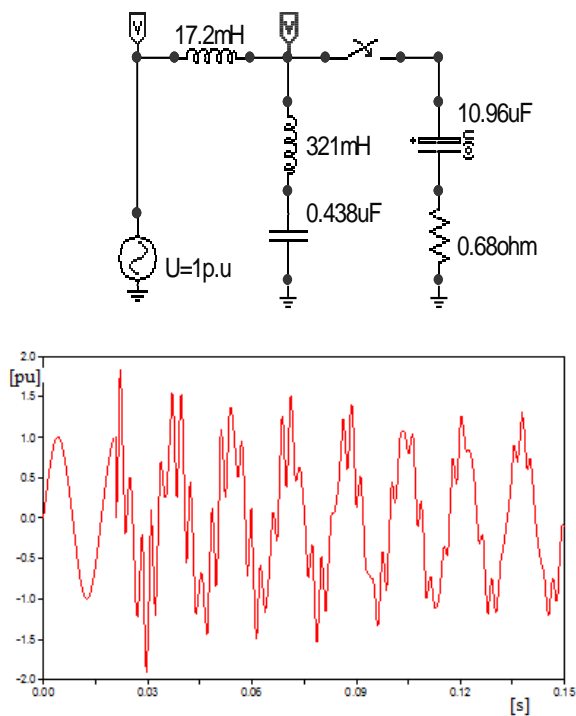


Figure 2. Simulation circuit & Voltage wave

2.3 Back to back Capacitor Switching

Overvoltage amplitudes of 1.5 pu may be reached when a capacitor bank is switched into other parallel banks already in operation in high voltage network

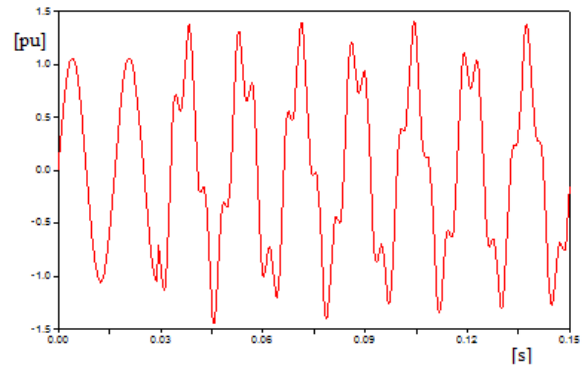
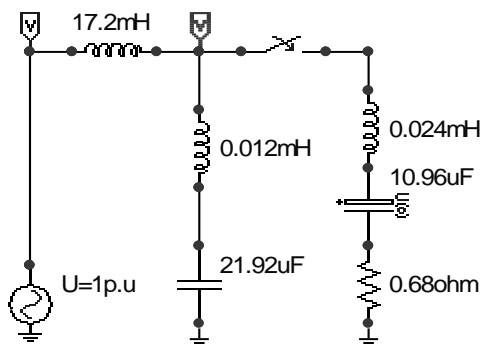


Figure 3. Simulation circuit & Voltage wave

2.4 Prestrike Capacitor Switching

During closing process, electrical field between the two contacts of circuit breaker attains such a value that incurs insulation breakdown. This phenomenon of prestrike happens well before capacitor closing, and voltage amplitude can reach 2.6 pu.

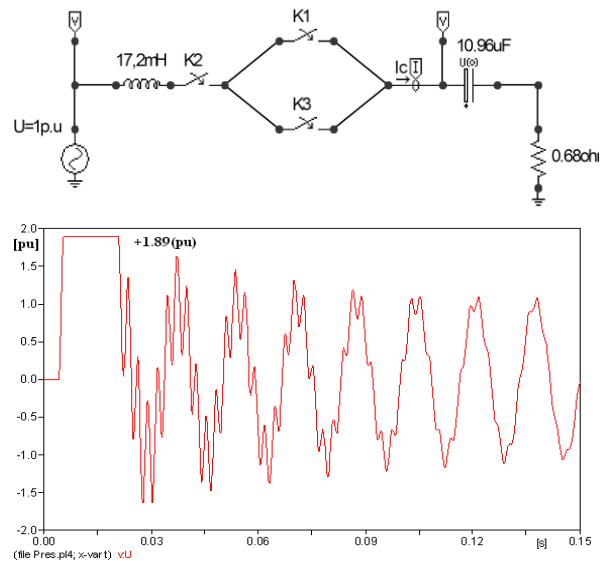


Figure 4. Simulation circuit & Voltage wave

2.5 Restrike Capacitor Switching

During breaking process, the voltage difference between circuit breaker contacts may reach to a value of 2 pu in excess of insulation withstand. An overvoltage of 3 pu may be reached during the first restrike, and second, third restrike may happen. In second restrike voltage amplitude can reach a value as high as 6.4pu.

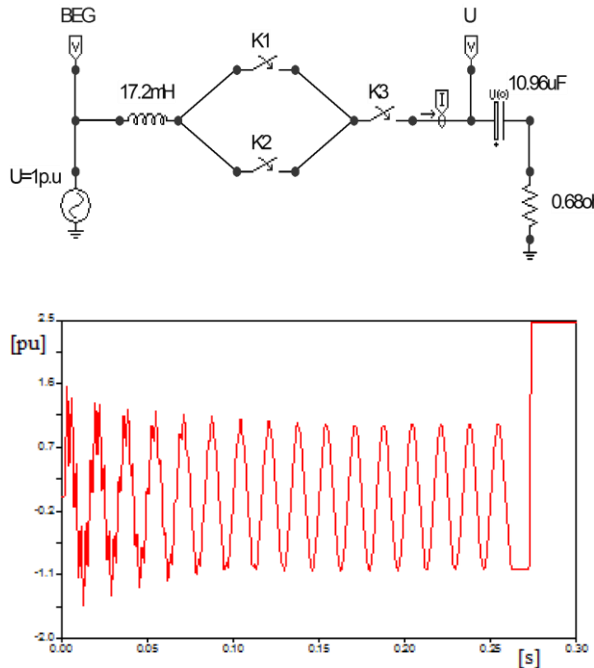


Figure 5. Simulation circuit & Voltage wave

3. APPLICATION OF DWT TECHNIQUE AND EXPERIMENTAL RESULTS

3.1 Multi-Resolution Analysis technique

The first main characteristic in DWT is the Multi-Resolution Analysis (MRA) technique that can decompose the original signal into several other signals with different levels (scales) of resolution (Fig.11). From these decomposed signals, the original time-domain signal can be recovered without losing any information.

The recursive mathematical representation of the MRA is as follows [1]:

$$\frac{1}{N} \sum_{k=1}^N (x[k])^2 = \frac{1}{N} \sum_{k=1}^N |u_j[k]|^2 + \sum_{j=1}^J \left(\frac{1}{N} \sum_{k=1}^N |w_j[k]|^2 \right) \quad (1)$$

With $x[k]$ is a discrete input, $k = 1 \dots N$

The first term on the right of (1) denotes the average power of the approximated version of the decomposed signal, while the second term denotes that of the detailed version of the decomposed signal. The second term giving the energy distribution features of the detailed

version of distorted signal will be employed to extract the features of power disturbance.

3.2 Detailed Energy Distribution

As seen in [2], the energy of the distorted signal can be partitioned at different resolution levels in different ways depending on the power-quality problem. Therefore, the coefficient of the detailed version at each resolution level will be examined to extract the features of the distorted signal for classifying different power-quality problems. The process can be represented mathematically by [1]:

$$P_j = \frac{1}{N} \sum_{k=1}^N |w[k]|^2 = \frac{\|w_j\|^2}{N} \quad (2)$$

Energy is normalized [1]:

$$P_j^D = (P_j)^{1/2} \quad (3)$$

In this paper, a 13-level decomposition of each discrete distorted signal will be performed to obtain the detailed version coefficients $w_1 \sim w_{13}$. Simultaneously, with formulas (3)-(4), each detailed energy distribution ($P_1^D \sim P_{13}^D$) can be obtained.

3.3 Duration and Amplitude of Transients

In general, when a transient disturbance occurs, the stable power signal will generate a discontinuous state at the start and end points of the disturbance duration.

Employing the DWT technique to analyze the distorted signal through three-level decomposition of the MRA will cause the wavelet coefficients w_3 at the start and end points of the disturbance to generate severe variation. Therefore, we can easily obtain the start time t_S and end time t_E of the disturbance duration from the variations in absolute wavelet coefficients w_3 and calculate the disturbance duration t_T [6]:

$$t_T = |t_E - t_S| \quad (4)$$

3.4 Experimental results

We can categorize three properties of energy distribution of the given distorted Capacitor Switching signals.

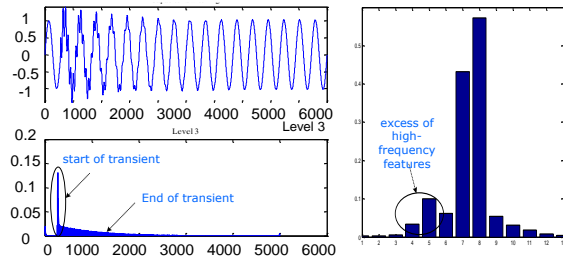


Figure 6. MRA decomposition and energy distribution diagram of isolated capacitor switching

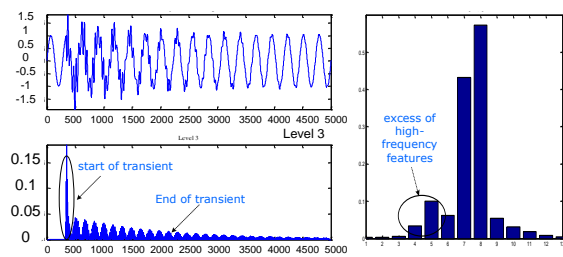


Figure 7. DWT and energy distribution diagram of voltage magnification of capacitor switching

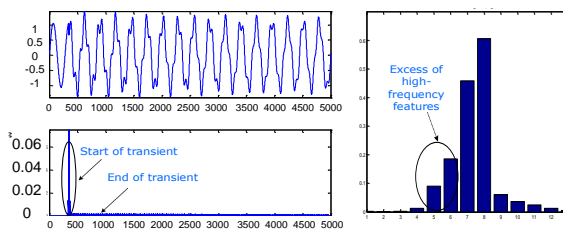


Figure 8. DWT and energy distribution diagram of back to back capacitor switching

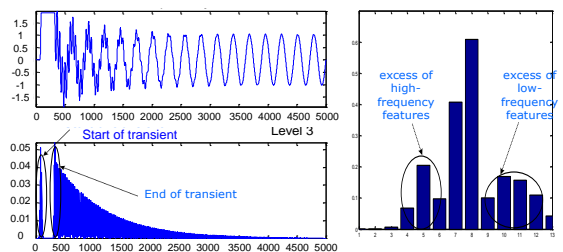


Figure 9. DWT and energy distribution diagram of prestrike in capacitor switching

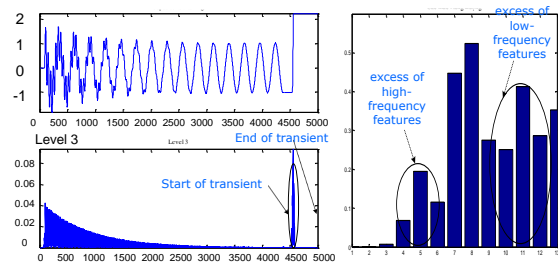


Figure 10. DWT and energy distribution diagram of restrike in capacitor switching

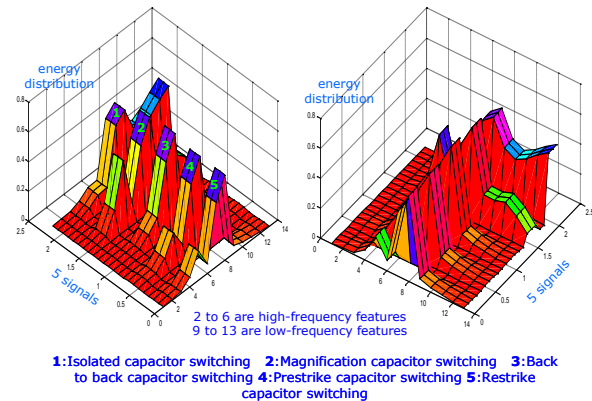


Figure 11. Differences in energy distribution of capacitor bank switching types.

Fig. 11 shows differences in energy distribution of power disturbances, in particular of capacitor bank switching transients.

3.4 Probabilistic Neural Network (PNN)

There are three layers in the PNN model with signal input in the first layer, which calculates from this signal to trained samples. The second layer calculates the probabilistic distribution of the input signal. Then the third layer determines the maximum probabilistic distributions of the input signals, and attaches the value of 1, otherwise the value of 0.

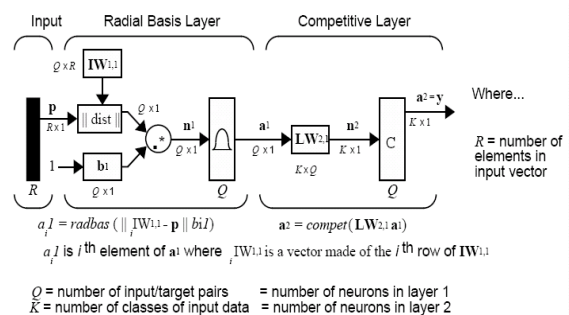


Figure 12. Probabilistic Neural Network model

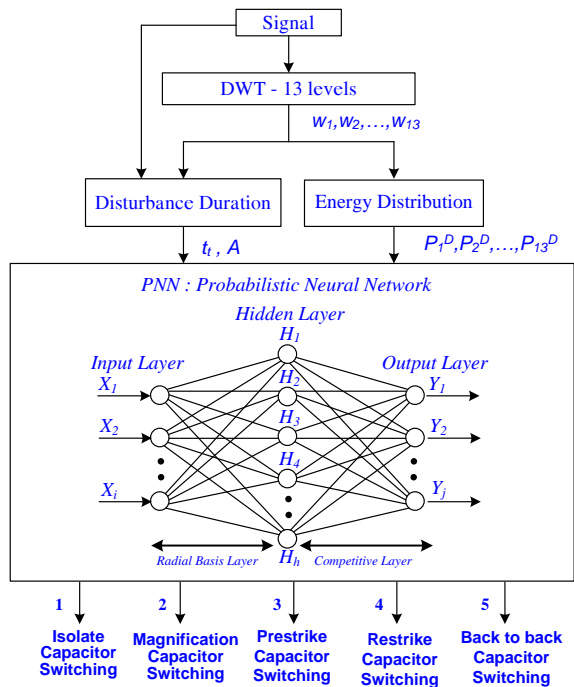


Figure 13. Diagram of a proposed classifier.

Inputs are 15 values of disturbances: 13 levels of energy distribution, transient duration and amplitude. Table 1 shows high results. The trained samples are 40 and 70 then accurate rates are 80% and 92% respectively. Test time per a sample is a cycle of a capacitor switching disturbance. These results can be applied in real-time power systems. The

accurate rate is higher when increased a training sample. This rate is the better result compared to that of the previous studies [1,7].

Table 1. Recognition results

Training samples	40	70
Test samples	15	25
Accurate sample	12	23
Accurate rate	80%	92%
Learning time (s)	0.18	0.2
Test time (s)	0.02	0.02

4. CONCLUSION

The identification and classification of power quality is a vital task for the precise monitoring of power systems. In this paper, a comprehensive technique based on the use of wavelet technique and artificial intelligences such as PNN method is made. It is shown that a method of classification has their own inherent advantages. Moreover, the method of classification of disturbances demonstrates the potential for the development of fully automated monitoring systems with on-line classification capabilities.

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