Classification of Power System Transients Using Discrete Wavelet Transform and Random Forest Method

Abdurrahman ÜNSAL[1] and Mustafa ERCİRE[2]

[1]Dumlupinar University, Department of Electrical and Electronics Engineering, Kutahya, Turkey
unsal@dpu.edu.tr, mustafa.ercire@dpu.edu.tr
[2]Dumlupinar University, Gediz Vocational School, Address, Gediz/Kutahya, Turkey

Abstract

Power system transients are the main power quality problems. Classification of the power system transients is a common problem in power quality studies. Impulsive and oscillatory transients are caused by a variety of sources in power system including natural and power system related. Their effects on power systems are also differ. Therefore, power system transients should be classified as impulsive and oscillatory correctly. In power quality studies, usually, the transients are not classified into impulsive and oscillatory. In this study power system transients are classified into impulsive and oscillatory groups by using discrete wavelet transform and random forest method. The implementation was realized in LabVIEW. The proposed classification method was tested by real power quality data. The results show that this method can be used successfully for the classification of power system transients.

1. Introduction

Power Quality (PQ) can be defined differently by utilities, equipment manufacturers, and customers. Utilities generally consider PQ as system reliability. On the other hand equipment manufacturers, consider PQ as being that level allowing for proper operation of their equipment, whereas customers consider PQ as good power that ensures the continuous operation of processes and businesses. A PQ problem is defined as being "any power problem manifested in voltage, current, or frequency deviations that result in failure or maloperation of customer equipment" [1].

Power quality problems can be classified into different categories. One of these problems is transients. Transients are studied along with other PQ problems such as swell, sag, outage, notches. In the PQ problems, "transient problem" is sometimes considered as "impulsive transient," "oscillatory transient," or just "transient." Transients are classified according to IEEE-1159:2009 standard as "impulsive and oscillatory." The classification is based on the spectral content, duration, and magnitude [2].

An impulsive transient is a sudden increase from the nominal condition of voltage, current, or both which is unidirectional (either positive or negative). The characterization of impulsive transients is done by their rise and fall times. An oscillatory transient is a sudden change in the steady state condition of voltage, current, or both which may contain both positive and negative polarity values. Since the duration of transients is less than one cycle, it must be sampled at a higher frequency compared to other power quality events in order to classify correctly.

In power quality studies, both impulsive and oscillatory transients are classified, generally, into one group as "transient [3, 4] based on waveform analysis." Since the real world transients can be originated from a variety of events and may have a very complicated characteristics, the mathematical model based studies which classify transients as "impulsive" and "oscillator" may not describe the real world transients completely [3, 5-8]. Since each cause of the transients are different they should be classified differently [2].

Many advanced signal processing techniques such as Kalman Filter, Wavelet, Stockwell, Hilbert-Huang, Gabor Transforms etc. are used in PQ studies. Artificial Intelligence Methods, Support Vector Machine and similar signal processing methods are used for feature extraction and classification of PQ problems. Random forest method is used recently in PQ studies [9-11]. The majority of these studies are focused on general determination of PQ problems. In this study random forest method is used for transient classification. The classification is based on Discrete Wavelet Transform (DWT) coefficients' energy levels as feature extraction vector.

2. Random Forest

Decision tree approaches, based on a single tree structure in the decision making process, are basic methods used in classification applications. The Random forest method is based on the principle of creating more than one decision tree [12]. To classify a new object, the input vector is evaluated on every tree in the forest. This evaluation process is expressed as a kind of voting for each tree. The tree that receives the most votes on all the trees in the forest is selected for classification [13].

The growth of each tree is as follows: If the number of cases is set to N, then N cases are sampled randomly with replacement from the original data. These sampled N cases will be the training set for the growing tree. If there are M input variables a number ($m \ll M$) is specified such that at each node m variables are randomly selected out of the M. The best split on the selected m is used to split the node. The value of m is kept constant during forest growing. Then each tree is grown the largest extent possible. There is no pruning in the forest.

The error rate of the forest depends on two factors. These are correlations between trees and the power of each tree. The increase of the correlation increases the error rate. A tree with a low error rate provides a strong classification. The increase of the strength of individual trees reduces the rate of forest failure.

3. Discrete Wavelet Transform and Energy Levels

Wavelet Transform is a Fourier Transform based signal analysis method. The J-level Wavelet Transform is given as follows [14]:

$$f(t) = \sum_n a_J(n)\phi(t-n) + \sum_n \sum_{j=0}^{J-1} d_j(n) 2^{j/2} \psi\left(2^j t - n\right) \quad (1)$$

where a_J, is the scaling factor, d_j, is the wavelet coefficient, $\phi(t)$ is the scaling function, $\psi(t)$ is the wavelet function, J is the max level, and t represents time.

DWT is used to obtain features of transients. Seven-levels of DWT were used in this study. In the DWT, the dB4 mother wavelet whose performance has been tested in the PQ is selected as the fundamental wavelet. The relationship between the energy in the transient signal x(t) each scale of the DWT coefficient can be calculated by using following equation [15].

$$1/_N \sum_t x(n)^2 = \sum_{j=1}^{N} \left|A_{i,j}\right|^2 + \sum_{j=1}^{N} \left|D_{i,j}\right|^2 \quad (2)$$

where, $i = 0,1,2....,l$. The energy values of the approximate and detail coefficients obtained from the DWT can be calculated by using the following equation:

$$EA_l = \sum_{j=1}^{N} |A_{i,j}|^2 \quad (3)$$

$$ED_j = \sum_{j=1}^{N} |D_{i,j}|^2 \quad (4)$$

4. Implementation

In this study, the records of real world transient events (which are not classified either impulsive or oscillatory) are studied by the proposed method. The real world event records are obtained from the power quality project, “POSC/EEA-ESE/57708/2004” which was implemented in Portugal [16]. The data was sampled at 50 kHz, and recorded with a length of 20 cycles, and 0.4 sec. The amplitude of the recorded transient signals is normalized. Fig. 1 shows a sample of the recorded transient event.

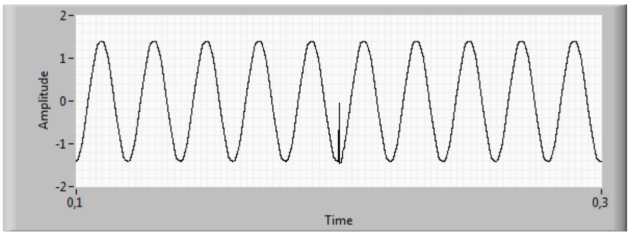

Fig. 1: Recorded Data

Preprocessing: Since the recorded signal contain all frequency components including fundamental component, transients, power harmonics, and other PQ problems related components the signal is preprocessed by removing the fundamental component and up to 7th harmonics. This is done in order to increase the accuracy of the proposed method. Then the pure transient signal is obtained. Fig. 2 show the pure transient signal obtained from preprocessing.

If 77% of the peak-to-peak of the magnitude of the pure transient signal is of one polarity then the signal is labeled as impulsive. Otherwise the transient signal is considered as oscillatory. The flow chart of this process is given in Fig. 3.

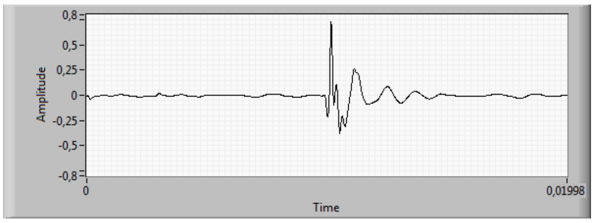

Fig. 2. Pure transient signal

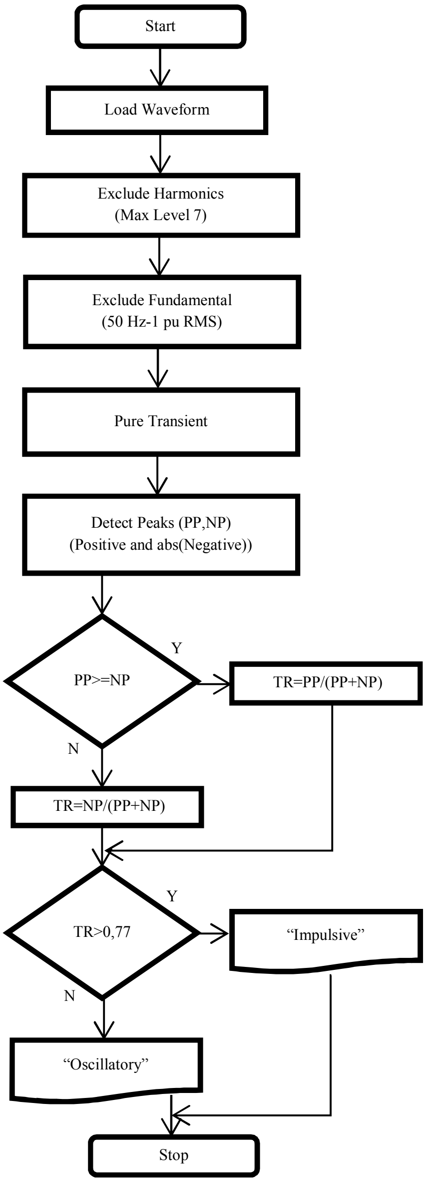

Fig 3. The preprocessing Flow chart

The preprocessing is implemented by using LabVIEW software tool (Fig. 4).

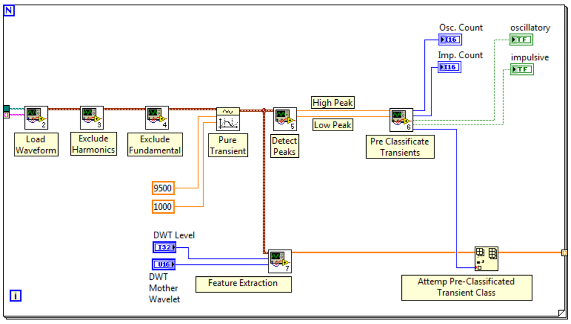

Fig. 4. Preprocessing block diagram

Feature Extraction: The feature extraction process is also implemented by using LabVIEW software tool (Fig. 5). The energy values of DWT coefficients (approximate and detailed) are calculated by using equations (3) and (4).

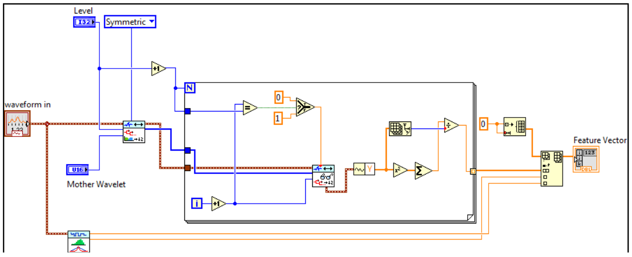

Fig. 5. Feature extraction block diagram

The transient signals may contain noise and high frequency harmonic components. The noise and high frequency components will affect the classification accuracy. In order to improve the classification accuracy of the proposed method kurtosis and skewness (which are given in equations (5) and (6)) of pure transient signal are calculated and used in feature vector given in Table 1.

$$\text{kurtosis (kurt)} = \frac{(\sigma - \mu)^4}{n * (\sigma)^4} \tag{5}$$

$$\text{skewness (skew)} = \frac{3(\mu - \tilde{\mu})}{\sigma} \tag{6}$$

Table 1. Feature vector

Feature Vector									
E_{D1}	E_{D2}	E_{D3}	E_{D4}	E_{D5}	E_{D6}	E_{D7}	E_{A7}	kurt	skew

5. Results

The proposed methods is tested by using the real transient data obtained from [16]. The real transient data is labeled and categorized as impulsive or oscillatory by using algorithm given in figure 3. Then energy values of DWT coefficients, skewness, and kurtosis values of the pure transient signal are calculated to construct the feature vector. The experimental data is categorized into five data-sets based on pu values of magnitude of the transient signals. The pu values are 0.15, 0.30, 0.45, 0.60, and 0.75. Each data-set is classified by employing random forest classifier. When the pu amplitude value of the transient is high the classification accuracy is also high. The lowest classification accuracy rate (97,5 %) is gained by processing data set with 0.15 pu while the highest classification accuracy rate (98,9 %) is gained from the data set with 0.75 pu. The results also show that the classification of impulsive transient gives higher accuracy rate compared to the oscillatory transient. It can also be seen from Table 2 that the peak-to-peak amplitude value based classifications can give satisfactory results.

Table 2. Classification Results

Data Sets	Events pu %	Events count	Classification Results (Confusion Matrix)				
1	>0,15	591		Imp	Osc	Accuracy (%)	
			Imp	322	7	97,9	97,5
			Osc	8	254	96,9	
2	>0,30	531		Imp	Osc	Accuracy (%)	
			Imp	286	5	98,3	98,1
			Osc	5	235	97,9	
3	>0,45	496		Imp	Osc	Accuracy (%)	
			Imp	274	5	98,2	98,0
			Osc	5	212	97,7	
4	>0,60	458		Imp	Osc	Accuracy (%)	
			Imp	267	4	98,5	98,5
			Osc	3	184	98,4	
5	>0,75	365		Imp	Osc	Accuracy (%)	
			Imp	251	1	99,6	98,9
			Osc	3	110	97,3	

6. Conclusions

One of the main problem of PQ studies is the classification of the power system transients. In this work, a discrete wavelet and random forest based power system transient classification system has been designed. The designed system has been tested with real data. The results show that discrete wavelet and random forest based system classifies the power system transients successfully.

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