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Identification of Power Quality Issues using Kalman Filter

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Abstract

A Kalman filter - generalized regression neural network based technique for the classification of power quality disturbances is presented here. A two stage classifier is proposed in which feature extraction is performed using a Kalman filter. Amplitude of the waveforms is the feature extracted from the Kalman filter and given as input to generalized regression neural network which classifies power quality disturbances. Distored waveforms on the power system model were simulated using Matlab software. Five classes of PQ disturbances were classified and the performance evaluation has been done using 500 signals, with a sampling rate of 128 per cycle of each signal.

Keywords: Kalman Filter, Neural Network, Power Quality, Power Quality Disturbances

1. Introduction

Power quality disturbances such as voltage sag, swell, outage, surge etc may lead to mal-operation or failure of any sensitive electric facilities. Power quality disturbance is defined as any deviation in the waveform magnitude, frequency or purity of the sinusoidal signal. Any diversion from the requirement is considered as poor quality. In order to improve power quality, the sources and causes of such disturbances must be known before appropriate mitigating action could be taken. A feasible approach to achieve this goal is to incorporate detection capabilities in to monitoring equipment so that events of interest will be recognized, captured and classified automatically. The major effect of disturbance at the load and analyze the source of the disturbances so that an appropriate solution is formulated. The commonly used feature extraction methods are Fourier Transform, Short Time Fourier Transform, S Tansform, Wavelet Transform etc. Fourier Transform provides accurate results for stationary waveforms in the absence of time varying harmonics. STFT analyses the signal whose spectrum changes with time. But the limitation of fixed window length makes this unsuitable for analysis of transient signals. The major problem of the traditional analyzing method is that it does not provide sufficient information on the time domain. To overcome these difficulties, Wavelet Transform is consider as suitable for analyzing signals with localized impulses and oscillation present in fundamental and low order harmonic signals.

S Transform is an alternate of Wavelet Transform for analyzing fundamental and harmonic component signals from S matrix, because of the use of scalable Gaussian window, S Transform perform superior to either of the transform. A new classification methodology based on machine inductive learning implemented using c4.5 algorithm decomposed with Wavelet Transform of original signal is proposed. A Wavelet – Neurofuzzy

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combined system for PQ violation, detection and diagnosis of non-stationary harmonic distortion in the Power system is presented. A novel classifier is performed by using neural network for Power quality application is presented.

An effective wavelet based feature extraction method for classification of Power quality disturbances using MLP neural network is proposed. A hybrid technique for classifying Power quality events through the feature extracted from Kalman filter and analysis of random signal is discussed^{11,12}. A modular neural network based approach requires lesser training time and has a training accuracy independent of the input pattern¹⁴. In this proposed work, a two stage system for classifying the power quality events is proposed. Classification of Power quality disturbances is done with the help of GRNN through the feature extracted from Kalman filter.

Covariance of this noise along with captured signal forms input to the Kalman filter. The disturbance classifier is based on GRNN and various disturbances such as Sag, Swell, interruption, Harmonics etc were simulated using MATLAB. Performance of the classifier is evaluated using 500 PQ disturbance signals.

2. Kalman Filter

The process to be estimated is described as

$$X_{k} = AX_{k-1} + W_{k-1}$$
 (1)

Where X_k and X_{k-1} are the state vectors at the instants k and (k-1) respectively, A is the state transtition matrix, W_k is the white noise whose covariance is calculated using DWT¹.

As power quality disturbances analysis is carried out using the voltage signals, the signals are represented using the equation of the form

$$Z_{k-1} = HX_{k-1} + v_{k-1}$$
 (2)

Where H is the matrix that gives the connection between measurement and state vector at time $\mathbf{t}_{k\text{-}1}$, $\mathbf{v}_{k\text{-}1}$ is the measurement error

The signals with a fundamental frequency of ω and different harmonic components are expressed as

$$Z_{k-1} = \sum_{i=1}^{n} M_i \sin((i\omega(k-1))\Delta T + \theta_i)$$
(3)

Where n represents the order of harmonics, M is the amplitude and ΔT represents the sampling interval. For the next interval k,

$$Z_{k} = \sum_{i=1}^{n} M_{i} \sin((i\omega k)\Delta T + \theta_{i})$$
(4)

Time update equations given by

$$\hat{X}_{k}^{-} = A \hat{X}_{k-1}^{\hat{}}
 P_{k}^{-} = A P_{k-1} A^{T} + Q$$
(5)

Where P_k represents a prior process covariance and Q_k is the covariance matrix of W_k .

Measurement update equations are given by

$$K_{k} = P_{k}^{-} H^{T} \left\{ \left(H P_{k}^{-} H^{T} \right) + R \right\}^{-1}$$

$$\hat{X}_{k} = \hat{X}_{k}^{-} + K_{k} \left(Z_{K} - H \hat{X}_{k} \right)$$

$$P_{k} = (I - K_{k} H) P_{k}^{-1}$$

$$(6)$$

Where R_k is the covariance matrix of v_k and K_k is the Kalman gain.

Time and measurement update equation (5) and (6) are alternatively solved. After each time and measurement update pair, the process is repeated using the previous posterior estimates used to project the new a prior estimates^{2,17}.

At any given instant k, the amplitudes of the fundamental and harmonic frequencies are computed from estimated variables as

$$A_{1,k} = \sqrt{X_{1,k}^2 + X_{2,k}^2} \tag{7}$$

$$A_{i,k} = \sqrt{X_{2i-1,k}^2 + X_{2,ki}^2}; i = 1,2,.....n$$
 (8)

3. Neural Network

Neural Networks (NN) incorporate two fundamental components of biological neural sets namely neurons and synapses which are otherwise termed as nodes and weights³⁻⁶. A neural network may have a few input and hidden layers and one or more output layers. Neural network are useful for many task such as pattern-matching and classification, function approximation, optimization and data clustering etc^{7,19}. A perceptron is a neuron with weighted inputs, which allows for some additional, fixed preprocessing of input data. The general regression neural network (GRNN) is a one-pass learning algorithm with a highly parallel structure. GRNN have four layers such

as Input layer - there is one neuron in the input layer for each predictor variable Hidden layer - this layer has one neuron for each case in the training data set8. The neuron stores the values of the predictor variables for the case along with the target value. Pattern layer/Summation layer - this layer has only two neurons in the pattern layer9,18. One neuron is the denominator summation unit the other is the numerator summation unit. The denominator summation unit adds up the weight values coming from each of the hidden neurons. The numerator summation unit adds up the weight values multiplied by the actual target value for each hidden neuron¹⁰. Decision layer - divides the value accumulated in the numerator summation unit by the value in the denominator summation unit and uses the result as the predicted target value. GRNN networks generate accurate predicted target probability scores in this work, Generalized regression based neural network is used as the classifier.

4. Proposed Method

A two stage classifier, which uses Kalman filter in stage1 for feature extraction and GRNN based neural network in stage 2 for disturbance classification is proposed in this work. The block diagram of the proposed method is shown in Figure 1. Various distorted signals together with the values of measurement error covariance of each of the measurement forms input for kalman filter¹¹.

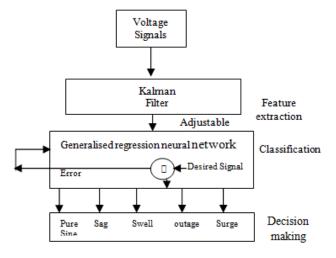


Figure 1. Block Diagram of the Proposed Method.

Process noise values are updated by the Kalman filter during each evaluation of the time and measurement update pair of equations. The neural network designed for this purpose is a 4 layer network with 1 neurons in the input layer, 10 neurons in the hidden layer, 2 neuron in the pattern layer and 5 neurons in the output layer¹². The initial weights and biases are randomly assigned and sigmoidal activation function has been used. The neural network has been trained using 100 test signals for each class through back propagation algorithm¹³⁻¹⁶.

5. Simulation and Test Results

The necessary voltage signals have been generated by simulating various types of disturbances on a Simulink model of the power system which has a voltage source connected to the load centre through a short transmission line as shown in Figure 2.

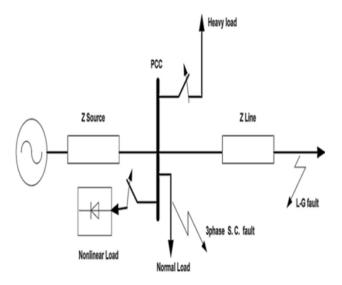


Figure 2. Simulink Model of the Power system.

Several types of disturbances namely pure sine, sag, swell, outage, surge etc were simulated and feature extraction of these signals was done through Kalman filter. The sampling rate chosen is 128 per cycle of each of the voltage signal with a frequency of 50Hz. Total size of the training data set is 1*500,where 1 represents the number of features extracted for each type of disturbance and 500 comes from 100 cases per class of disturbance multiplied by five classes. The PQ disturbance signals generated using the Matlab simulink and the training performance of neural network with200epochs are shown in Figures 3 to 7 for various classes of disturbances.

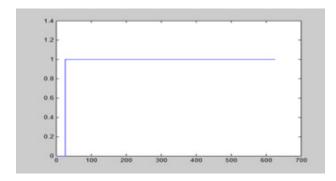


Figure 3. Voltage(pu) vs sample points Normal.

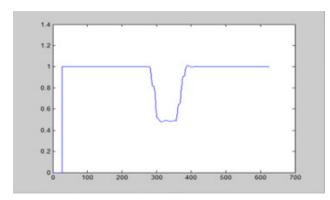


Figure 4. Voltage(pu) vs sample points SAG.

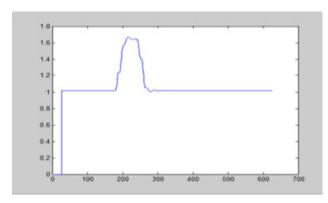


Figure 5. Voltage(pu) vs sample points SWELL.

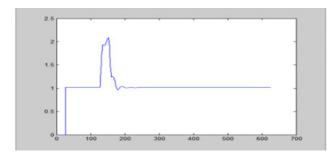


Figure 6. Voltage(pu) vs sample points SURGE.

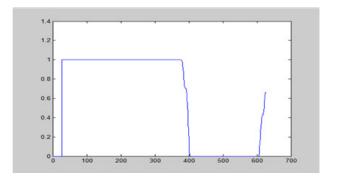


Figure 7. Voltage(pu) vs sample points OUTAGE.

6. Conclusion

In this paper a Kalman filter – generalized regression neural network based method is proposed for the classification of PQ disturbances. A Power system model with heavy load, normal load and non-linear load has been realized using Matlab simulink software and various disturbances such as Pure sine, sag, swell, outage, and surge were simulated on this model and they form input to the Kalman filter which performs the feature extraction. Amplitude of each of the disturbance class waveform is the extracted feature which forms input to the GRNN based neural network.

It has been found that the proposed method classifies the disturbances with sufficient accuracy. The results presented clearly shows the potential capability of the proposed work in classifying the distorted PQ signals accurately even under noise condition.

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