Electrical Power and Energy Systems 82 (2016) 197–206

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Conjugate gradient back-propagation based artificial neural network for real time power quality assessment

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ARTICLE INFO

Article history:
Received 10 September 2015
Received in revised form 27 November 2015
Accepted 9 March 2016
Available online 24 March 2016

Keywords:
ANN
Back-propagation
Monitoring
Power quality
Real time system

ABSTRACT

This paper proposes conjugate gradient back-propagation based artificial neural network for real time power quality assessment. The novel real time voltage sag and swell detection, classification scheme using artificial neural network is presented. The ANN is trained in MATLAB using voltage sampled signal data and corresponding parameters of the neural network are utilized to implement in LabVIEW in real time sag swell detection and classification. The Levenberg Marquardt, the resilient back-propagation and conjugate back-propagation algorithm performance is evaluated in MATLAB to find the best neural network for real time application. Among these three back-propagation algorithms, conjugate gradient algorithm has better performance for real time power quality monitoring. The mathematical model of Conjugate gradient back-propagation neural network is implemented in LabVIEW. Real time voltage signals of sag and swell for different time duration and magnitude, intensity are acquired from hardware experimental setup. Hardware setup mainly consists of single phase 230 V voltage source, microcontroller, dimmerstat and solid state relays. Voltage signals of sag and swell are sensed using high precision voltage sensor. Data acquisition system is used to acquire the signal from voltage sensor. The output of data acquisition system is given to the personal computer with LabVIEW. The proposed monitoring system also detects odd and even harmonic components in the voltage signal acquired using FFT. Real time hardware results obtained using proposed power quality monitoring system for detection of voltage sag, swell and harmonics claims the suitability, robustness and adaptability to monitor power quality issues.

Introduction

The power quality term comes from the concept that the AC voltage applied to the household equipment and industrial quipment must be pure sinusoidal and its magnitude as well as frequency must be in the range decided by IEEE and IEC standards. Nowadays the quality of power degraded due to the use of different power electronics equipment and adjustable speed drives. The excessive use of electronics introduces the disturbances like voltage sag, swell, harmonics, flicker, transients, etc. These disturbances can affect the performance of programmable logic devices, personal computers and variable speed drives which can lead to the power losses and efficiency reduction [1,2]. The household equipments like laptops, televisions, refrigerators, etc. are highly affected by the power quality disturbances. Poor power quality leads to malfunctioning of computers, lights flicker, blink or dimming of light, malfunctioning of microwave and noise interference to communication lines, etc. So it is very important to mitigate these disturbances to avoid the loss of power and money. Mitigation of the particular disturbance is possible only if that disturbance is accurately detected and classified. So it is very important to continuously monitor the power system data so that the proper mitigation of the problem can be done.

In the last two decades, several methods are proposed as Fourier transform, wavelet transform, S transform, Kalman filters for the detection of disturbances [3–10]. The Fourier transform is a very basic method when it comes to the detection of disturbances, but it has certain limitations like it can't give the time and frequency analysis of signal at the same time. To overcome this limitation short time Fourier transform and wavelet transform are introduced which can give time information and frequency information at the same time. Still the problem persists that the transformation methods cannot be used in real time. The industry requires the method to analyze the enormous amounts of power system data that are streaming in. Hence; there are some methods proposed which can continuously monitor the voltage and current in real time. For the automatic classification, methods like decision

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http://dx.doi.org/10.1016/j.ijepes.2016.03.020
0142-0615/

trees, artificial neural network, fuzzy logic, support vector machine are introduced which can be implemented in real time monitoring. The detailed review of power quality monitoring methods is given in [11].

The artificial neural network (ANN) has proven to be the suitable method for real time power quality monitoring [11]. Combination of transformation methods and neural network is widely presented in literature. The combination of adaptive linear network and feed forward neural network for the detection and classification of disturbances in single phase system is proposed in [12]. In [13] Statistical and wavelet based hidden Markov model with Dempster–Shafer algorithm is used for monitoring. In [14] Image processing is used for the identification of disturbances. S transform and extreme learning machine based automatic recognition system for disturbances is proposed in [15]. Power quality analysis with the help of sparse signal decomposition on hybrid dictionaries is done in [16]. The hybrid method including wavelet for feature selection, modified relief, sequential forward and sequential backward selection is used for PQ monitoring in [17]. In [18] Discrete S transform and a decision tree based monitoring system is presented. Neural network based reconfigurable instrument is proposed in [19]. FPGA based real time monitoring system is proposed in [20]. Feature extracted signal is used while using a combination of neural network and transformation techniques. Discrete wavelet transform and hyperbolic S transform based PQ monitoring system is proposed in [21]. Features are extracted with the help of transformation techniques which are difficult to implement in real time and can be time consuming. To avoid this issue, only neural network with the help of a proper training algorithm can be used for monitoring. For training of neural network different back-propagation techniques are used. Levenberg Marquardt (LM), Resilient back-propagation, Conjugate gradient back-propagation (CGB) algorithm are some of the techniques which are used for training. These algorithms have various representations and different structure. Hence; these can be used for different applications. In general the Levenberg Marquardt algorithm is mainly used for curve fitting problems where as conjugate gradient or the scaled conjugate gradient algorithm is mainly used for pattern recognition problem.

The S transform based real time monitoring system proposed in [22] is implemented in LabVIEW. This paper proved that the LabVIEW software can be used as an instrument which can monitor the power quality in real time. This same idea in the form of artificial neural network is implemented in the proposed monitoring system. In this paper, a conjugate gradient backpropagation algorithm based neural network is implemented in LabVIEW for real time power quality monitoring. The use of this algorithm and its implementation in LabVIEW for real time PQ monitoring is not reported in the literature. Hence an effort is made to use this algorithm in real time.

Artificial neural network for PQ monitoring

Artificial neural network

Artificial neural network (ANN) is the network formed by the artificial neurons. These neurons are interconnected just like biological neurons. The neural network can form the adaptive system which can change its behavior based on the information flowing inside and outside the network. An ANN can be used for specific applications like data classification, pattern recognition by the learning process. In this paper ANN is used to recognize the waveforms of voltage sag, swell and to classify it accordingly. The neural network can be trained by certain learning rules which are called as training algorithm. Basic back-propagation is a training algorithm which has certain limitations like time required for training is more. But because of its popularity, there is a large development in this algorithm to converge the training as fast as possible. The use of optimization techniques like conjugate gradient algorithm, Levenberg–Marquardt and the resilient back-propagation algorithm made the back-propagation algorithm faster [23]. In this paper these three algorithms are studied for the training process.

Training process

Data generation for training the network

Sampled data to train the ANN is generated using the mathematical equations in MATLAB. These equations are

$$V_{normal} = A_1 \sin(\omega t + \theta) \quad (1)$$

$$V_{sag} = A_1 \sin(\omega t + \theta) - A_2 \sin(\omega t + \theta) \quad (2)$$

$$V_{sag} = A_1 \sin(\omega t + \theta) + A_2 \sin(\omega t + \theta) \quad (3)$$

Voltage sag is defined as the decrease in rms value of voltage from 0.9 pu to 0.1 pu for the time period 0.5 cycle to 1 min. Voltage swell is defined as the increase in rms value of voltage from 1.1 pu to 1.8 pu for the time period 0.5 cycle to 1 min. MATLAB program is developed using above Eqs. (1)–(3) to generate these disturbances. For example, normal voltage signal is generated by using Eq. (1) from 0 to 0.4 s with $A_1 = 325$, $\omega = 314$ rad/s and $\theta = 0$. Then to create voltage sag, Eq. (2) is executed from 0.4 to 0.5 s with $A_2 = 110$. Again for normal voltage Eq. (1) is executed from 0.5 s to onwards. Similarly Eqs. (1) and (3) are used for generation of voltage swell. 500 hundred samples of voltage sag and swell are generated with different magnitude and time period according to the definition.

Performance evaluation of training algorithm

Three networks are trained with the help of data generated for training. One thousand samples are given to the network as an input vector. Target is set as 1 for sag or swell otherwise 0 in case of conjugate gradient method. This is due to presence of logsigmoid function. This function does not allow any other target, that is other than 0 and 1. The same target is assigned to the Resilient back-propagation method. In case of Levenberg–Marquardt method target can be set as any number due to the linear transfer function, so it is set as 2 for sag/swell and 0 for normal signal. 60 percent of input samples, that is 600 samples are used for training. While training the network to get desired output, No. of neurons in network increased in steps. It was observe that the network trained with 100 neurons gives satisfactory performance. Hence; the network consists of 100 neurons and 2 hidden layers. For validation 20 percent and for testing 20 percent samples are used. Performance of training is characterized by mean squared error which is the average squared difference between output and target. When the value of the error is sufficiently small, the training process ends. The performance of training is shown in Fig. 1. The case of conjugate gradient method is shown in Fig. 1(a) and in case of Levenberg–Marquardt in Fig. 1(b). It is seen that the minimum squared error in case of Levenberg–Marquardt method is achieved at 44 epochs and in case of conjugate gradient method it requires 74 epochs. Fig. 1(c) shows the case of Resilient back-propagation, the minimum squared error is 0.09807 and achieved at 17 epochs. As the validation error starts increasing training process is ended. After ending the training process, trained network is formed. Gradient in case of Levenberg–Marquardt method is 0.00188 at 50 epochs and in case of conjugate gradient method is 0.01079 at 80 epochs. So it is clear that resilient back-propagation requires less iterations than Levenberg–Marquardt and conjugate gradient method for the same data. Hence; it is concluded that training process is faster in case of Resilient method than LM and Conjugate gradient method.