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Adaline and Its Application in Power Quality Disturbances Detection

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Abstract: In the paper, some problems of the methods that are used to analyze the power quality issues are firstly pointed out. A kind of Artificial Neural Networks, Adaline, and its new algorithm for analysis of power quality are presented. The new algorithm has the advantages of being simply calculated and easily implemented through hardware. The simulating results of voltage quality disturbances detection demonstrate that the new Adaline and its algorithm can be applied to the precise analysis for power quality disturbances.

Keywords: power quality, voltage quality, disturbance detection, Adaline

1. Introduction

In the last few years, there is a great increase in the use of computers and other microprocessor based applications. These new generations of electronic equipment are becoming progressively sensitive to power quality disturbances. Any variation in the supply voltage magnitude or frequency may result in very expensive consequences. So the quality of electric power has become an important issue for electric utilities and their customers.

Several methods have been developed to detect the power quality disturbances. Point-by-point comparison on two adjacent power cycles is the primitive way [1]. When a certain threshold is reached, the disturbance is recognized. This method has many drawbacks: firstly, it is insensitive to steady state power quality phenomena, such as harmonics; secondly, this method is sensitive to the chose threshold value, which means a low threshold value will make fake disturbance detection and a high threshold value may overlook many real disturbances.

Discrete Fourier Transform (DFT) is widely applied as the base of modern frequency spectrum analysis [2, 3]. It is especially effective to analyze the steady signal which doesn't vary with time. To unstable signal, any change in time domain will affect the whole frequency domain, and DFT is limited under this condition.

Wavelet transform has been successfully utilized as a power quality disturbance detector as the high frequencies associated with power quality disturbance could be distinguished and localized in time using low scale levels [4,5]. Through wavelet transform, the information of both time domain and frequency domain can be extracted. However, this technique suffers from being dependent on the basis wavelet utilized for the detection. And both DFT and wavelet transform need a great deal of calculation.

Recent years, with the development of artificial intelligence technique, artificial neutral network has been used to analyze the power quality [6, 7, 8]. Based on adaptive linear neutron network (Adaline), a method of power quality analysis by time locating is brought forward in this article. While in the process of Adaline's training, the changing of the input signal's character can be tracked immediately by the changing of network's error. Thus, when the change of amplitude of the voltage takes place, the learning error of the Adaline can change correspondingly, so the change of power quality can be distinguished out. This method is simple in calculation and easy to be realized by hardware, so it has very strong actual meanings. The principle of Adaline is expounded briefly in the second part of this article, locating of disturbance in voltage quality by Adaline is expatiated in the third part.

2 Adaline

2.1 Adaline architecture

Adaline was firstly proposed by Widrow and Hoff

[9, 10] from Standford University. An Adaline is a multi-input, single-output, single layer linear neural element, and its characteristics are:
(1)Train on-line based on the changing inputs and the target response;
(2)Self adaptive algorithm can be applied to the weights training;
(3)Simple structure makes it easily implemented on hardware.
Graphically, an Adaline is represented by the construction shown in Fig.1.

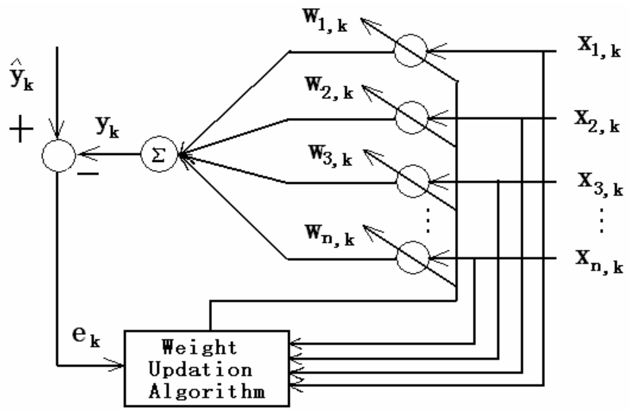

Fig.1 Adaline diagram

Where
k is the time index;
$X_k = [x_{1k}, x_{2k}, \cdots, x_{nk}]$ is the input vector;
$W_k = [w_{1k}, w_{2k}, \cdots, w_{nk}]$ is the weight vector;
$y_k = \sum_{i=1}^{n} w_{ik} x_i = W_k X_k^T$ is the network output;
$e_k = \hat{y}_k - y_k$ is the error;
$\hat{y}_k$ is the target output.

2.2 Adaline training algorithm

Training algorithm is the main characteristic of the artificial neural network, and the training process of Adaline is also the process of modifying the weights of the network. Through this, the error between target output $\hat{y}_k$ and real output y_k can be minimized. Widrow-Hoff learning rules are adopted. Firstly, an output error function of the linear network is defined as:

$$E = \frac{1}{2}\sum_k [\hat{y}_k - y_k]^2 = \frac{1}{2}\sum_k [\hat{y}_k - W_k X_k^T]^2 \qquad (1)$$

Because E is dependent on the weights and the target output, we can regulate the weights to minimize E. Widrow-Hoff learning rules are based on an approximate steepest descent procedure.. Widrow and Hoff had the insight that they could estimate the mean square error by using the squared error at each iteration. If we take the partial derivative of the squared error with respect to the weights and biases at the kth iteration we have

$$\Delta w_{ik} = -\eta \frac{\partial E}{\partial w_{ik}}$$
$$= \eta[\hat{y}_k - W_k X_k^T] x_{ik} = \eta e_k x_{ik} \qquad (2)$$

Where
η is the learning rate, generally $0 < \eta < 1$.
If η is large, learning occurs quickly, but if it is too large it may lead to instability and errors may even increase. To ensure stable learning, the learning rate must be less than the reciprocal of the largest eigenvalue of the correlation matrix $X^T X$ of the input vectors. Thus, weight increase is

$$\Delta W_k = \frac{\eta e_k X_k}{X_k^T X_k} \qquad (3)$$

Where
$0 < \eta < 1$.
To produce a faster convergence in the presence of random noise, a non-linear weight adaptation algorithm is desirable. Rewritten the weight adjustment algorithm as:

$$\Delta W_k = \frac{\eta e(k)\theta(X)}{X^T \theta(X)} \qquad (4)$$

Where

$$\theta(X) = \begin{bmatrix} SGN(x_1) \\ SGN(x_2) \\ \vdots \\ SGN(x_n) \end{bmatrix},$$

With

$$SGN(x) = \begin{cases} +1, if \ x \ge 0 \\ -1, if \ x < 0 \end{cases}$$

Widrow-Hoff learning rules make the change of the net weights have a direct proportion to the output error and the inputs of the Adaline. This algorithm doesn’t need to calculate the derivatives, so it can be computed simply and make the Adaline converge fast.

2.3 Training process of Adaline

Training process includes three steps:

(1) Calculate the network output $y_k = \sum_{i=1}^{n} w_{ik} x_i = W_k X^T$ and the error $e_k = \hat{y}_k - y_k$;

(2) Compare the network output sum square error E and the target error E_0, if E is smaller than E_0 or the training times already reach the maximum times limit, stop training, else go on.

(3) Calculate new weights $W_{k+1} = W_k + \Delta W_k$, and return to step (1).

3 Voltage quality disturbances detection by using Adaline

According to the space reconstruction theory of Takens, Adaline is used to track voltage changes. The equation of a model can be described below:

$$y(t) = f(y_{(t-1)}, y_{(t-2)}, \ldots, y_{(t-n)}, U(t), U(t-1), \ldots, y_{(t-m)}) \quad (5)$$

Where n is the input order, m is the output order. There are two method can be used to train Adaline: one is using the delay of real system's output as the model's input to train the Adaline, which can be used in online calculation, control, and single step prediction, the other is to train the Adaline using the output delay of the model itself as input, for in offline calculation and multi-step prediction, the output delay of real system is unknown to the model. In order to fit for offline calculation, the second method of Adaline training is used in this article, and the output delay of the model itself is used. Conceptual diagram is shown as Fig.2.

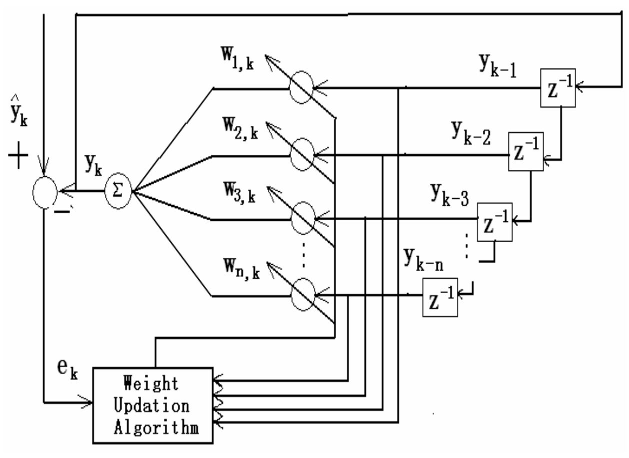

Fig.2 the conceptual diagram for Adaline with time delays

The adopted detection system is a n-input single output MISO system. The model can be expressed as:

$$y_k = f(y_{k-1}, y_{k-2}, y_{k-3}, \ldots, y_{k-n}) \quad (6)$$

When voltage quality changes, the voltage sudden change will cause the error raise of the Adaline, and the weights of Adaline vary with it. The variation of error signal can aid the voltage disturbances detection. Different voltage quality events such as voltage sag, voltage swell, voltage interruption, harmonics and transients have been simulated using Matlab software. These signals can test the Adaline's ability of detecting voltage disturbances.

3.1 Voltage sag

Voltage sags are usually associated with system faults but can also be caused by switching of heavy loads or starting of large motors. So it occurs most frequently among all the voltage disturbances [11]. Fig.3 shows the input voltage and the tracking signal waveforms for typical sag. The corresponding error signal and the square root of it are also shown in Fig.3. The square root of the error signal magnifies the effect. At the moment the sag starts and ends, average magnitude of the square root of the error varies sharply. Through this, the time the sag occurs and ends can be precisely recorded.

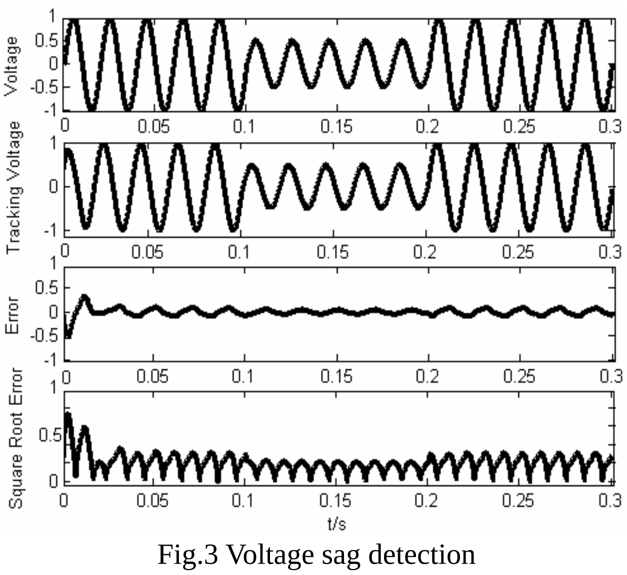

Fig.3 Voltage sag detection

3.2 Voltage swell

As with sags, swells are usually associated with system fault conditions, but they are much less common than voltage sags. A swell can occur due to a single line-to-ground fault on the system resulting in a temporary voltage rise on the unfaulted phases.

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Swells can also be caused by switching off a large load or switching on a large capacitor bank. Voltage swell may cause damage to electronic equipment and may cause redundant protective relays operation [11]. Fig.4 shows the input voltage and the tracking signal waveforms for a typical swell. The corresponding error signal and the square root of the error signal are also shown in Fig.4. As well as voltage sag, at the moment the sag starts and ends, average magnitude of the square root of the error varies sharply. Through this, the time the swell occurs and ends can be precisely recorded.

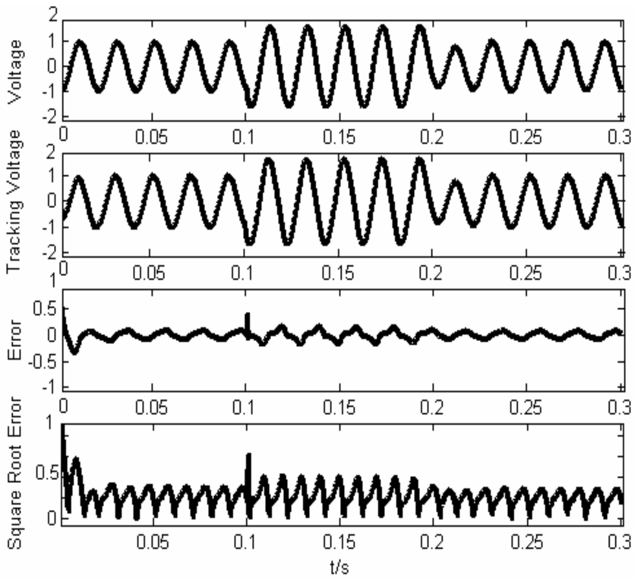

Fig.4 Voltage swell detection

3.3 Sudden outage

Sudden outage can be the result of power system faults, equipment failures, and control malfunctions. The outages are measured by their duration since the voltage magnitude is always less than 10% of nominal [11]. Fig.5 shows the input voltage and the tracking signal waveforms for typical sudden outage. The corresponding error signal and the square root of it are also shown in Fig.5. More obvious than both voltage swell and voltage sag, at the moment the sag starts and ends, average magnitude of the square root of the error varies sharply. Through this, the time the sudden outage occurs and ends can be precisely recorded.

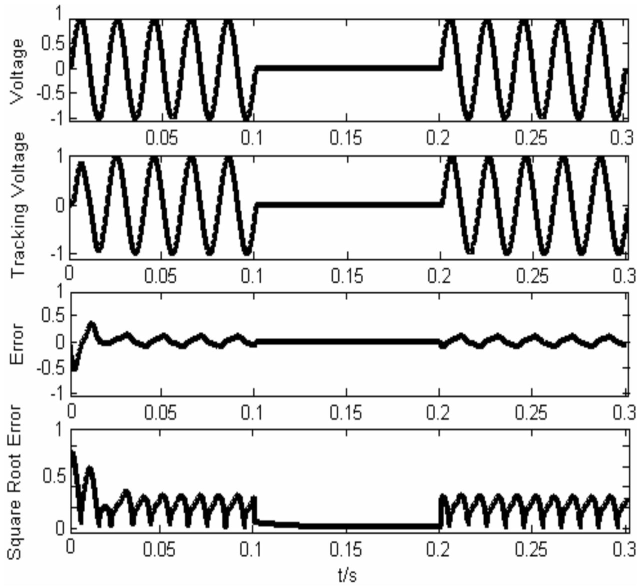

Fig.5 Sudden outage detection

3.4 Harmonics

Harmonic distortion originates from the nonlinear characteristics of devices and loads on the power system. It is a growing concern for many customers and for the overall power system due to increasing application of power electronics equipment [11]. Fig.6 shows the input and the tracking voltage waveforms for a typical signal contaminated with harmonic distortion. In addition, Fig.6 offers the corresponding error signal and the square root of the error signal. At the moment the harmonics starts and ends, average magnitude of the square root of the error varies sharply. Through this, the time the harmonics occurs and ends can be precisely recorded.

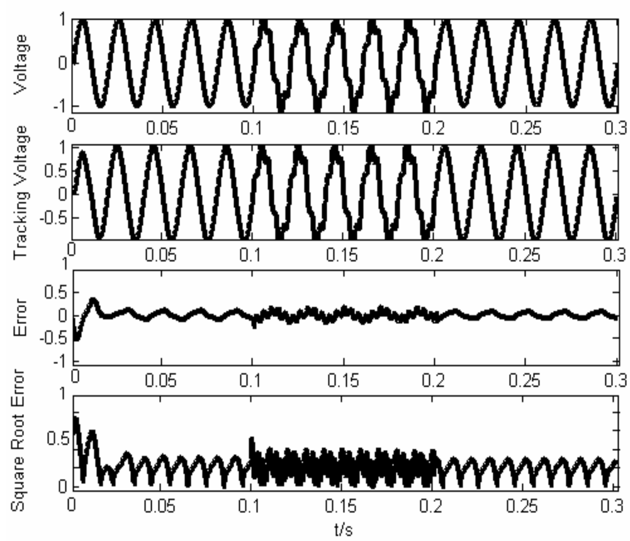

Fig.6 Detection of harmonics

3.5 Transient

Transient voltages caused by lightning or switching operations can result in degradation or immediate dielectric failure in all classes of equipment [11]. Fig.7 shows the input and the tracking voltage waveforms for a typical signal of transient. In addition, Fig.7 offers the corresponding error signal and the square root of the error signal. At the moment the transient starts and ends, average magnitude of the square root of the error varies sharply. Through this, the time the transient occurs and ends can be precisely recorded.

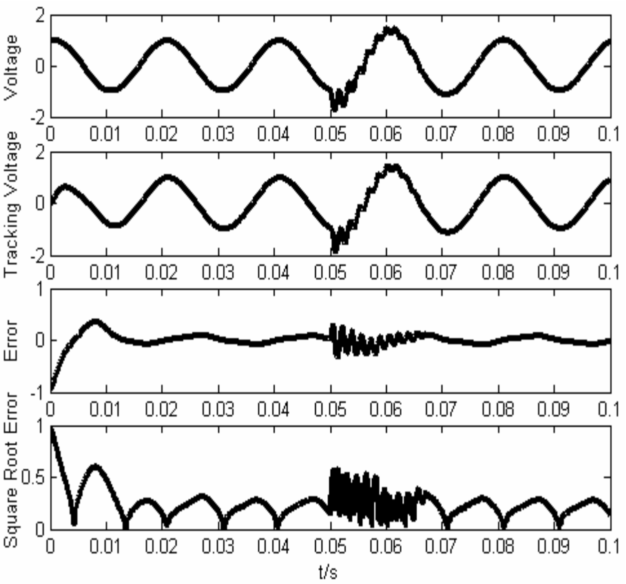

Fig.7 Detection of transient

3.6 Hybrid disturbances

In this section, a combined scenario is assumed to validate the continuous operation of the Adaline. Fig.8 illustrates a voltage waveform, which contains sudden outage and voltage sag events. The corresponding prediction error signal is also given in Fig.8. when the average magnitude of the square root of the error varies, the occur time can be precisely recorded.

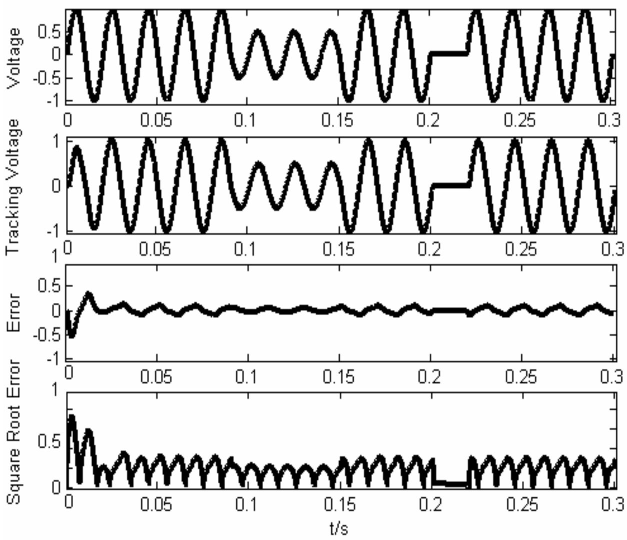

Fig.8 Detection for hybrid disturbances

4 Conclusions

Variation in the supply voltage magnitude may have detrimental effects on the equipment which is sensitive to power quality. Adaline which is multi-input, single-output, on-line training single layer linear neural element is introduced in this article. It is used in voltage disturbance detection. Simulation result shows its good performance. For Adaline's simple architecture, it's easy to be implemented through hardware and has a good application prospect.

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