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Technical note

A self-synchronized ADALINE network for on-line tracking of power system harmonics

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ABSTRACT

This paper presents a modified adaptive linear neuron (ADALINE) structure, called self-synchronized adaptive linear neuron (S-ADALINE) network for fast and accurate estimation of power system harmonics. The proposed network relies on the Levenberg gradient descent (LGD) method based parameter updating rule and is capable of dealing with both nominal and off-nominal frequency conditions, rather than the existing modified Widrow–Hoff delta rule based ADALINE network which provides good accuracy only at nominal frequency. Moreover, the S-ADALINE provides faster response and better noise immunity than the conventional approach. The only flaw of the proposed network is its high computational load. Based on simulation studies, performances of the proposed harmonic estimator at different operating conditions have been presented and its accuracy and response time have been compared with the conventional ADALINE structure.

1. Introduction

The increasing utilization of non-linear and sensitive loads, for instance the power supplies in computers, communications and consumer electronics, leads to gradual deterioration of electric power quality. Estimation of the harmonic components is a standard approach for the assessment of this power quality problem.

Among various harmonic spectral analysis algorithms, the discrete Fourier transform (DFT) is the most commonly used technique [1]. However, in applying the DFT the phenomena of aliasing, leakage and picketfence effects may lead to inaccurate estimation [2]. Moreover, it has limitation in detecting short term time-varying signals. Although the short-time Fourier transform (STFT) is introduced to analyze non-stationary power system signals, the problems inherited from the DFT still cannot be improved effectively [3]. To overcome this problem, the discrete wavelet transforms (DWT) based power components estimation algorithm has been presented in [4]. But, slow attenuation of quadrature mirror filter banks (QMF) and the overlay of the pass bands of different levels, strongly influence the frequency decomposition of the DWT and introduce significant error. Moreover, it is often difficult to extract the fundamental or any other single harmonic component of the signal using this method. Kalman filter [5], Newton type algorithm [6] and time domain techniques [7] are examples of some well known alternative approaches. However, for real-time use these methods have trade-off between accuracy and speed. The search for more accurate, computationally simple and robust algorithm still continues.

In recent years, the adaptive linear neuron (ADALINE) structure have attracted much attention and have been widely used as harmonic estimator due to their simple structure and non-stationary signal parameter tracking capability. Dash et al. [8] first utilize ADALINE network for on-line tracking of power system harmonics. After that, various modifications in weight updating rule [9–11] or internal structure [12–14] have been proposed to improve accuracy and response time. However, estimation results

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of all these methods have been significantly deteriorated at off-nominal frequency conditions. Although the frequency deviation is considered in [15–17], the on-line application of these methods is restricted due to computational complexity or convergence problem.

In this paper, a modified ADALINE structure has been proposed in which the fundamental frequency has been treated as an unknown parameter and simultaneously estimates it with the tracking of the harmonic components. To improve the accuracy and response time of the proposed method, instead of conventional improved Widrow–Hoff rule, Levenberg–Marquardt method has been utilized for parameter up-gradation. The resulting ADALINE structure, called self-synchronized adaptive linear neuron (S-ADALINE) network, is system frequency insensitive and provides better accuracy and faster response time than the conventional ADALINE structure. The presented simulation results confirmed these facts.

2. Harmonic detection with the conventional ADALINE networks

If, the discrete time input signal $y[n]$ with the fundamental angular frequency ω_r contains a finite number of significant harmonics with maximum order M, then at any sample instant n, it may be represented by the Fourier series of the form [8–11]

$$\begin{aligned} y[n] &= \sum_{k=1}^{M} Y_k \sin(k\omega_r n + \alpha_k) \\ &= \sum_{k=1}^{M} Y_k \sin(k\omega_r n)\cos\alpha_k + \sum_{k=1}^{M} Y_k \cos(k\omega_r n)\sin\alpha_k \\ &= \sum_{k=1}^{M} A_k \sin(k\omega_r n) + \sum_{k=1}^{M} B_k \cos(k\omega_r n) \end{aligned} \quad (1)$$

where Y_k and α_k are the amplitudes and phase angles of kth harmonic, respectively, $A_k = Y_k \cos \alpha_k$, and $B_k = Y_k \sin \alpha_k$.

Rearrangement of (1) in a matrix form gives:

$$y[n] = (W[n])^T x[n] \quad (2)$$

where

$$W[n] = [A_1\ B_1\ A_2\ B_2\ \cdots\ A_M\ B_M]^T \quad (3)$$

and

$$\begin{aligned} x[n] = [&\sin\omega_r n\ \cos\omega_r n\ \sin 2\omega_r n\ \cos 2\omega_r n \\ &\cdots\ \sin M\omega_r n\ \cos M\omega_r n]^T \end{aligned} \quad (4)$$

T indicates transpose of a vector quantity. If ω_r is known *a priori*, the conventional ADALINE network can be utilized to track the unknown parameters $W[n]$ from known values of time varying connection matrix $x[n]$.

The general architecture of the conventional ADALINE network for harmonic estimation has been presented in Fig. 1 [8–11]. The known input vector $x[n]$, at any sample instant n, is multiplied by the adjustable weighting vector $W_A[n] = [G_1\ H_2 \cdots G_M\ H_M]^T$, and then summed to produce the estimated signal $\hat{y}[n]$. Hence

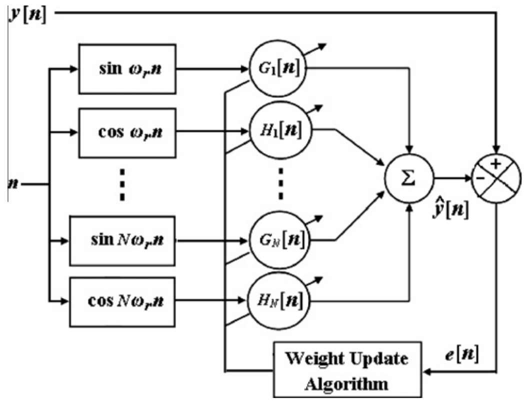

Fig. 1. The architecture of the conventional ADALINE network.

$$\hat{y}[n] = \sum_{k=1}^{M} G_k \sin(k\omega_r n) + H_k \cos(k\omega_r n) = (W_A[n])^T x[n] \quad (5)$$

The error signal $e[n]$ is the difference between the desired signal $y[n]$ and the estimated signal $\hat{y}[n]$, and can be expressed as:

$$\begin{aligned} e[n] &= y[n] - \hat{y}[n] \\ &= y[n] - \sum_{k=1}^{M} G_k \sin(k\omega_r n) + H_k \cos(k\omega_r n) \\ &= y[n] - (W_A[n])^T x[n] \end{aligned} \quad (6)$$

After the initial random estimation, an adaptive algorithm updates the weight vector $W_A[n]$ of the conventional ADALINE network so that the output $\hat{y}[n]$ ultimately reaches to the desired signal $y[n]$. The conventional steepest descent method based weight up-gradation rule, also known as modified Widrow–Hoff delta rule, is given by [8–11]

$$W_A[n+1] = W_A[n] + \frac{\eta_{wh} e[n] p[n]}{(x[n])^T p[n]} \quad (7)$$

where η_{wh} is the learning parameter and $p[n] = sgn(x[n])$.

After the tracking error $e[n]$ converges to zero or a predefined value, $W_A \approx W$, and the amplitude and phase of kth harmonic is estimated as [8–11]

$$S_N = \sqrt{W_A^2(2k-1) + W_A^2(2k)} \quad (8)$$

$$\alpha_N = \tan^{-1} \frac{W_A(2k-1)}{W_A(2k)} \quad (9)$$

3. Proposed harmonic estimator

The conventional ADALINE structure, as presented in the previous section, provides erroneous results at off-nominal frequency conditions [14], and thus, incompatible for real time power system signal analysis. In order to achieve faster convergence and self-synchronizing property, this paper suggests two modifications of the conventional ADALINE structure: Levenberg gradient descent method [18,19] based weight up-gradation and tracking