Harmonic Estimation in Power Systems Using Adaptive Perceptrons Based on a Genetic Algorithm

S.GHODRATOLLAH SEIFOSSADAT, MORTEZA RAZZAZ, MAHMOOD MOGHADDASIAN, MEHDI MONADI
Department of Electrical Engineering
Shahid Chamran University
Shahid Chamran University,Golestan Zone, Ahwaz
IRAN
seifossadat@yahoo.com

Abstract- With the widespread use of power electronics equipment and nonlinear loads since the last twenty years, current and voltage waveforms of distribution systems are becoming highly distorted. This paper presents an adaline artificial neural network, and its new algorithm based on a genetic method for tracking the harmonic components of current and voltage waveforms in power systems. Adaptive tracking of harmonic components can easily be done using this algorithm. The proposed algorithm is fast due to its simple construction, which make it suitable for on-line applications. This knowledge would make it possible to compensate the harmonic components. The simulated results are presented and validated by experimental results to depict the effectiveness of the proposed method.

Key-Words: - Adaline Neural Networks, Genetic Algorithms, Harmonics Estimation, Power System

1 Introduction

In the last few decades, power systems are often subject to harmonic injections due to increasing applications of nonlinear loads. The existence of harmonics in power system could cause serious problems such as voltage distortion, increased losses and heating and miss operation of protective equipment [1]. Any variation in the supply voltage magnitude or frequency may result in very expensive consequences and can act directly on the performance of electronic sensitive equipment such as computers and microprocessor based systems. So the power quality has become an important issue for electrical utilities and their customers.

Estimation of the harmonic components in a power system is a standard approach for the assessment of quality of the delivered power. Consequently, to provide the quality of the delivered power, it is imperative to know the harmonic parameters such as magnitude and phase. This is essential for designing filters for eliminating and reducing the effects of harmonics in a power system.

Various digital signal processing techniques have been suggested for measurement and estimation of power system harmonics. Traditionally, the harmonic analysis can be based on the theories of static and dynamic estimation. Some of the theories used are examples of static estimation: Least-Squared Method (LSM), the Discrete Fourier Transform (DFT) and recursive DFT, Fast Fourier Transform (FFT), spectral observer and Hartley transform [2]. On the other hand, the Kalman Filter is an example of a dynamic estimation.

In both methods, static and dynamic, the presence of incorrect data in the measurements (input data) has a significant effect in the performance of the estimation. The LS technique is based on the minimization of the mean square error between the estimated and the measured values of a function. In power systems, the state variables estimated are the voltage and current magnitudes and phase angles. For a non-linear model of the system, this technique results in a reasonable estimation of the parameters [3]. The DFT technique is based on the theory of orthogonal functions, where the waveform measured consists of a fundamental component increased by an infinite number of harmonics. However, misapplication of the DFT algorithm can lead to incorrect results. The computational cost of the algorithm is very low, but its performance can be affected by the DC component present in the signal [4].

The FFT algorithm developed by Cooley and Tukey is also used to estimate the harmonic content for waveforms varying in time and it is an optimized version of the DFT [5]. However, the application of the FFT may also lead to incorrect results especially due to pitfalls such as aliasing, leakage and picked fence effect [3].

The fixed gain [6] and variable gain [4] Kalman filter are based on a dynamic estimation of the signal and they have the ability to identify, analyze and locate the harmonic contents in a non-stationary signal. Despite presenting accurate results, previous statistical analysis of the signal is necessary.

The application of Artificial Intelligence (AI) technology in electric power systems has been an active area of research and significant improvements have been achieved in the last years. AI techniques have also been applied to harmonic identification in power systems. One of these methods, based on Artificial Neural Networks (ANNs), can be used as an on-line digital system to read and update electrical signals concerning harmonic parameters. ANNs have produced good results in noisy environments.

To predict the voltage harmonics, [7] has used the artificial neural network based on the back propagation learning technique. An analogue neural method of calculating harmonics is presented in [8] which uses the optimization technique to minimize error. This is an interesting application from the point of view of VLSI implementation.

In [1], a new method, based on linear adaptive neural network (Adaline) has been utilized to harmonic estimation. There are two major variables which control the adaline performance in detecting harmonic components. These factors are the learning rate η and the number of inputs, **N**, introduced to the adaline [4].

Another technique based on AI, namely the Genetic Algorithms (GAs), has attracted attention as a robust algorithm for stochastic search applied to optimization problems and it has been used to solve several problems in electric power systems with good results [9].

In this paper a new method based on Genetic Adaline Perceptrons (GAP) is presented to minimize the error signal and accurate estimation of harmonic components. This method uses GA to selection the optimized value for η. The proposed method is compared to the classical DFT, standard Kalman filter (KF), traditional adaline and GA method for its validation.

2 The Harmonic Model

Mathematically, a periodic and distorted signal can be suitably represented in terms of its fundamental frequency and harmonic components, and can be expressed as a sum of sinusoidal waveforms referred to as the Fourier series. Each frequency is an integer multiple of the fundamental system frequency. In order to obtain an approximation of such waves, mathematical models are employed. Consider a voltage waveform with harmonic components, written as (1)

$$\hat{y}(t) = a_0 + \sum_{n=1}^{N} \left[a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t) \right] + \varepsilon(t) \quad (1)$$

Where a_n and b_n are the coefficients, and N is the number of harmonics, ω_0 is fundamental angular frequency, $\varepsilon(t)$ is the noise and t is the instant of measurement.

3 Adaline Neural Networks

Adaline is firstly proposed by Widrow and Hoff [10, 11]. An adaline is a multi-input, single-output, single layer linear neural element. Graphically an adaline network is represented by construction shown in fig.1. Where k is time index or number of iteration; and the input on network is

$$x(k) = [\sin\theta \;\; \cos\theta \;\; \sin 2\theta \;\; \cos 2\theta \;\; \cdots \;\; 1 \;\; -kT_s]^T \quad (2)$$

where $\theta = \frac{2\pi k}{Ns}$ and Ns is sample rate.

Also, DC signal is modeled using two terms of Taylor series as

$$y_{DC} = A_{DC} - A_{DC}\alpha_{DC} kT_s \quad (3)$$

where T_s is the sampling time.

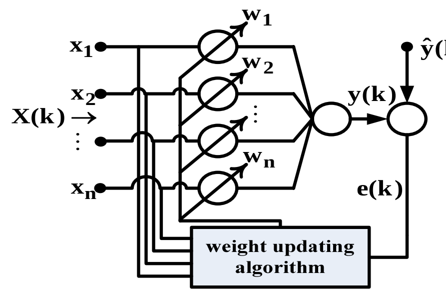

Fig 1. Block diagram for the adaline

The network output is

$$y(k) = \sum_{i=1}^{N} w_i(k)x_i = W^T(k)x(k) \tag{4}$$

The error signal is $e(k) = \hat{y}(k) - y(k)$. where $\hat{y}(k)$ is the desired output.

Training algorithm is the main characteristic of artificial neural network, and the training process of adaline is also the process of modifying the weight using the Widrow-Hoff delta rule as:

$$W(k+1) = W(k) + \frac{\eta\, e(k)\, x(k)}{\lambda + x^T(k)x(k)} \tag{5}$$

where λ is a small quantity to make $\lambda + x^T(k)x(k) \neq 0$. The error e(k) will be brought to zero, when perfect learning is attained and the weight vector will yield the Fourier coefficients of the signal. η is the learning rate and is chosen by GA. It must consider between $0 < \eta < 2$ to ensure Lyapunov stability and making the tracking error *e(k)* converge to zero[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 produce a faster convergence in the presence of random noise, a nonlinear weight adaptation algorithm is desirable. Rewritten the weight adjustment algorithm as

$$W(k+1) = W(k) + \frac{\eta(k)e(k)X(k)}{\lambda + x^T(k)X(k)} \tag{6}$$

Where

$$X(k) = [SGN(\sin\theta) \quad SGN(\cos\theta) \quad \cdots \quad 1 \quad -1]^T$$

The learning parameter η can be made adaptive by using the following expression

$$\eta(k) = \frac{\alpha}{1 + k/\beta} \tag{7}$$

where α and β are constant values. Widrow–Hoff learning rules change the net weights which have a direct proportion to the output error and the inputs of the adaline. This algorithm does not need to calculate the derivatives, so it can be computed simply and make the adaline converge faster and more accurate than other methods like FFT algorithm.

4 Implementation of a GA

GA was created by professor Holland, which is set up on the base of Darwin’s evolutionism and Meng DeEr’s hereditary theory. It imitates the gene recombination and the natural evolution course to solve the problem.

Essentially, a GA tries to minimize or maximize the value presumed by the fitness function. In many cases, the development of a fitness function can be based on this return. Additionally, the algorithm must be fast, because it will analyze each individual from a population and its successive generations [12].

The first step of the GA is the representation and codification of the problem parameters. Binary coding was used, since it is the traditional approach for GAs. Then a simple genetic algorithm is composed of three operators consist of selection, crossover, and mutation. Selection is a process in which individuals are copied to the mating pool according to their fitness. In this study, this operation was implemented with Roulette Wheel method, where each individual from the population is represented in the roulette proportionally to its fitness value. After selection, crossover proceeds to create offspring individuals. Members of the mating pool are mated at random.

In [13], a GA method has been developed for estimation of Fourier coefficients in (1) to minimize the error signal. The GA characteristics in this algorithm are shown in Table 1.

Table 1.
The GA Characteristics in [2]

Population size	50
Number of bits for binary codes	10
Crossover rate	two points (rate=97%)
Mutation rate	two points (rate=5%)
Fitness function	$\frac{1}{0.00001 + \sqrt{\frac{\sum_{k=1}^{N} e_k^2}{N}}}$
Stop criteria	10000 generation in each iteration

5 Proposed Algorithm

The proposed method (GAP) uses GA to selection the optimized value for learning parameter η, in each iteration for adaline, instead of (7) in the traditional algorithm. The GA characteristics of Adaline's Learning Optimization Process are shown in Table 2.

Table 2.
The GA Characteristics of a Adaline's Learning Optimization Process

Population size	10
Number of bits for binary codes	8
Crossover rate	single point

	(rate=97%)
Mutation rate	single point (rate=2%)
Fitness function	$e_k(\eta_k) = \hat{y}_k - W_k(\eta_k)x$
Stop criteria	average fitness exceeding or 500 generation in each iteration

6 Numerical Experiments

This work proposes the use of GAP in the on-line tracking of power system harmonics. The main purpose of the paper is to identify the various harmonic frequencies present in the signal. Taking that into consideration, a transmission line fault situation was simulated using ATP. When a fault occurs on a transmission line, radical changes occur in the voltage and current waveforms. The phase and magnitude of the 60 Hz voltage and current signal is badly corrupted by noise, in the form of a DC offset (exponentially decaying transient) as well as frequencies above 60 Hz. Figures 1 and 2 show a typical situation of a fault on a transmission line. A single-phase to ground fault is used since it is the most common type in a system of this nature.

The fault is applied at a voltage peak since this is the worst condition concerning transients. Once the voltage and current waveforms are determined, their harmonic content can be analyzed. The Fourier analysis is used to find the frequency content of the waveforms. Equation 7 and 8 describe its mathematical expression, respectively.

$$V(t)=0.0388\exp(0.4t)+0.4994\cos(wt)+0.3230\sin(wt)+0.0708\cos(2wt)+0.0224\sin(2wt)+0.0154\cos(3wt)+0.0165\cos(4wt)+0.0219\sin(4wt)+0.0176\cos(5wt)+0.0119\sin(5wt)+0.0120\cos(6wt)+0.0289\sin(6wt)+0.0084\cos(7wt)+0.0084\sin(7wt)+e(t) \quad (8)$$

$$I(t)= 0.0454\exp(0.4t)+0.4662\cos(wt)+0.0817\sin(wt)+0.0519\cos(2wt)+0.0543\sin(2wt)+0.0305\cos(3wt)+0.0218\cos(4wt)+0.0313\sin(4wt)+0.0178\cos(5wt)+0.0244\sin(5wt)+0.0159\cos(6wt)+0.0196\sin(6wt)+0.0157\cos(7wt)+0.0168\sin(7wt)+e(t) \quad (9)$$

The signals are corrupted by random noise (e(t)=Krand(t)) of zero mean, normal distribution and variance equal to unity. The amplitude of the noise (K) is chosen as 0.05 for this study. A sampling rate of 256 samples per cycle (Ns = 256) based on a 60Hz waveform is used for numerical computation.

Tables II and III present the average and standard deviation for each estimated parameter by the DFT from [5], KF from [6], GA from [13], adaptive perceptrons from [1] and the GAP respectively. Fig.4 shows a comparison between this various harmonic evaluation methods in estimation in first cosine coefficient of (8).

7 Conclsion

In this paper, a new method for on-line tracking of power system harmonics is proposed. The approach is based on the weight vector estimation of an adaline using weight adjustment algorithm based on GA. This method was tested using a voltage and current waveform of a transmission line fault situation. The results were compared to the other harmonic evaluation methods. Results show that the DC component estimated by new algorithms is much better than Fourier method. Also the results show that the GA has minimum deviation, although it is not as fast as other methods like Adaline and GAP structure. The Adaline algorithm is the fastest method and the GA is the most accurate one. So the GAP can be applied as a good trade off between speed and accuracy for harmonic evaluation in power systems.

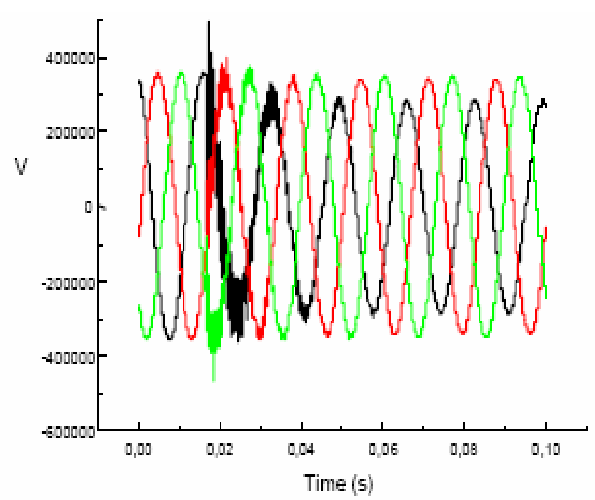

Fig 2. Voltage of a faulted power system

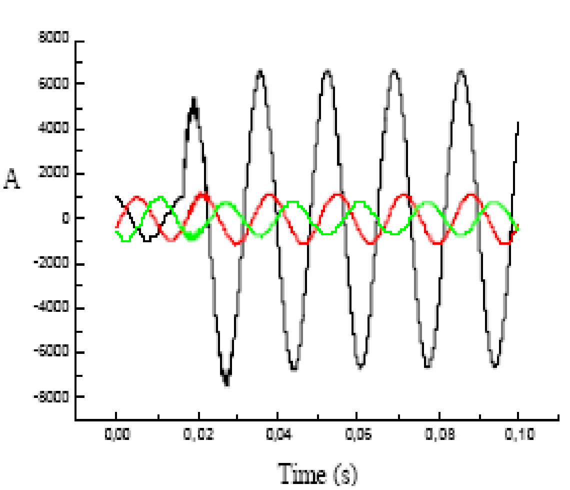

Fig 3. Current of a faulted power system

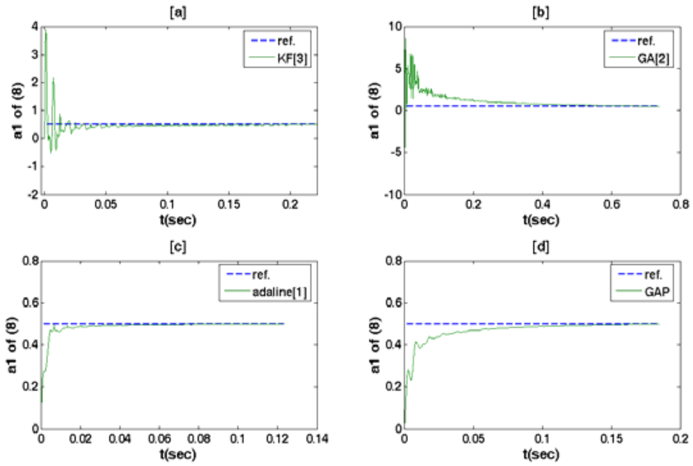

Fig. 4. Comparing various harmonic tracking methods
(a): KF[3], (b): GA[2], (c): adaline[1], (d): GAP

VALUES OF (5) AND (7) $\alpha = 1$, $\beta = 30$, $\lambda = 0.0001$

TABLE 3
FOURIER COEFFICIENTS OF VOLTAGE WAVEFORM

Target Harm. Order	Target Value	DFT [7]	DFT Error (%)	KF [3]	KF Error (%)	GA [2]	GA Error (%)	ADALINE [1]	ADA. Error (%)	GAP	GAP Error (%)
0 (DC)	0.0388	0.0685	102.62	0.0382	1.4309	0.0372	10.047	0.0348	2.9165	0.0350	3.5503
1C*	0.4994	0.5001	0.1496	0.5006	0.2336	0.5024	0.5937	0.4996	0.0416	0.4897	1.9423
1S*	0.3230	0.3227	0.1054	0.3187	1.3185	0.3233	0.0926	0.3335	3.2457	0.3071	4.9226
2C	0.0708	0.0715	1.0147	0.0697	1.5628	0.0719	1.5288	0.0727	2.7321	0.0748	5.6497
2S	0.0224	0.0232	3.3849	0.0239	6.7659	0.0242	7.9358	0.0251	11.967	0.0233	4.0179
3C	0.0154	0.0156	1.0184	0.0128	17.177	0.0174	12.895	0.0177	15.182	0.0172	11.688
4C	0.0165	0.0170	3.1294	0.0176	6.3639	0.0161	2.3394	0.0163	1.1702	0.0193	17.970
4S	0.0219	0.0219	0.0272	0.0231	5.4419	0.0260	18.508	0.0254	15.786	0.0230	5.0228
5C	0.0176	0.0180	2.5565	0.0175	0.3406	0.0200	13.831	0.0182	3.2055	0.0196	11.364
5S	0.0119	0.0127	6.4635	0.0102	14.088	0.0127	6.3801	0.0132	10.784	0.0132	10.924
6C	0.0120	0.0125	2.3903	0.0115	3.8917	0.0125	2.4291	0.0145	18.816	0.0131	7.3770
6S	0.0289	0.0291	0.5287	0.0302	4.5092	0.0297	2.8422	0.0298	2.9837	0.0266	7.9585
7C	0.0084	0.0088	4.2188	0.0112	32.885	0.0100	19.360	0.0100	19.267	0.0090	7.9585
7S	0.0084	0.0090	7.6545	0.0114	36.030	0.0089	6.0618	0.0103	22.672	0.0073	13.952
Average Error			9.6612		9.4315		7.4889		9.3406		7.9732

TABLE 4
FOURIER COEFFICIENTS OF CURRENT WAVEFORM

Target Harm. ORDER	Target VALUE	DFT [7]	DFT Error (%)	KF [3]	KF Error (%)	GA [2]	GA Error (%)	ADALINE [1]	ADA. Error (%)	GAP	GAP Error (%)
0 (DC)	0.0454	0.0818	107.65	0.0411	9.4335	0.0499	13.261	0.0349	6.2368	0.0350	0.5526
1C	0.4662	0.4671	0.1785	0.4695	0.7064	0.4694	0.6415	0.5006	2.7624	0.4897	2.5749
1S	0.0817	0.0816	0.0181	0.0866	6.0243	0.0850	1.0276	0.3345	0.6011	0.3071	0.9181
2C	0.0519	0.0528	1.2850	0.0519	0.0737	0.0556	5.1813	0.0733	5.1479	0.0748	0.3180
2S	0.0543	0.0552	4.1719	0.0476	12.414	0.0554	4.8044	0.0249	2.4249	0.0233	5.7947
3C	0.0305	0.0307	1.4857	0.0289	5.4045	0.0329	15.516	0.0164	11.270	0.0172	6.3744
4C	0.0218	0.0226	4.7686	0.0254	16.611	0.0248	17.888	0.0166	14.653	0.0193	9.7387
4S	0.0313	0.0315	0.9007	0.0331	5.9027	0.0322	3.9026	0.0254	9.3861	0.0230	5.2530
5C	0.0178	0.0185	4.2456	0.0175	1.9036	0.0184	3.3960	0.0180	4.7250	0.0196	8.9592
5S	0.0244	0.0248	3.0568	0.0284	16.432	0.0214	25.351	0.0119	8.7810	0.0132	6.8649
6C	0.0159	0.0169	8.3835	0.0125	21.476	0.0171	9.8222	0.0130	24.338	0.0131	29.161
6S	0.0196	0.0197	0.4904	0.0182	6.9573	0.0204	2.6895	0.0297	11.534	0.0266	10.850
7C	0.0157	0.0164	7.8590	0.0116	26.084	0.0168	13.184	0.0098	19.337	0.0090	10.897
7S	0.0168	0.0169	1.5748	0.0153	8.9153	0.0167	1.1627	0.0092	9.3262	0.0073	16.140
Average Error			10.4341		9.8815		8.4163		9.3262		8.5284

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