Harmony Search Optimization-Based Direct Estimation of Harmonic Components

Y. Ramya Sree, Bh. Sudharani, K. Sravan Kumar, D. J. V. Prasad, and Ch. Durga Prasad

Abstract In this paper, harmony search (HS) method has been employed for estimating the accurate harmonic components present in voltage/current waveforms of power system, since the metaheuristic algorithms are more attractive for intricate optimization to solve the problems of nonlinear in nature with the high degree of variables. Unlike conventional estimation approaches, direct curve fitting-based approach is adopted in this paper for the nearest and quick estimation of different harmonic components of distorted voltage signals. Comparative assessment of the HS algorithm with particle swarm optimization (PSO) reveals the advantages in terms of convergence and accuracy.

Keywords Harmonics · PSO · Harmony search algorithm

1 Introduction

In the modern power system, the use of microprocessor-based controllers and power electronic-based devices is enlarged. This leads to power quality problems and harmonic pollution [1]. The harmonics components will result in some adverse effects such as malfunction of relays and heating of components. To reduce harmonic

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pollution, it is necessary to determine harmonic parameters. The harmonic parameters include amplitude (A), phase angle (φ) and frequency (f). With these estimated parameters, the harmonics are eliminated by connecting some devices to the power system [2, 3].

Several techniques such as conventional, optimization, neural networks (NN) and hybrid algorithms have been implemented for harmonics estimation and tested. The discrete Fourier transform (DFT) [4] is one of the old conventional fast feasible algorithm. But, it does not give actual results and unstable for a few undesirable conditions. The fast Fourier transform (FFT) [5] is an advanced extension of the discrete Fourier transform (DFT). The FFT is the best technique for a static signal, and it does not perform well for time-varying signals. Kalman filtering method [6] is a simple way to estimate parameters. But it needs prior statistics of the signal. The least square techniques RLS [7] and LMS [8] are the best algorithms used so far. The values obtained by these estimation algorithms are closer to the actual values. But, these have certain drawbacks in terms of inaccuracies due to the existence of some variable parameters and noise. Some optimization techniques PSO, generic algorithm (GA) and artificial bee colony (ABC) are presented in [9–13]. These are the most effective algorithms for interharmonics, signals with noise and dynamic signals estimation. The estimation by these algorithms is carried out in one phase. So far the hybrid techniques [14–19] are considered, and these techniques are derived by combining the conventional least square algorithms with evolutionary algorithms and NN-based algorithms. The main objective of integrating the least square algorithms with other techniques is to reduce the error and to improve the accuracy of the estimation. The main drawback of these hybrid approaches is the estimation carried out in two phases. The amplitudes of harmonics are estimated by the least square technique, and the fundamental and other harmonic frequency components are estimated by other techniques.

In this paper, harmony search (HS) algorithm is implemented to estimate the parameters of the harmonics directly based on curve fitting approach by search-based mechanism. This algorithm is the best choice in terms of accuracy, computational time and convergence.

2 Problem Formulation

The general representation of distorted voltage and/or current signals of known fundamental frequency f is

$$x(t) = \sum_{h=1}^{N} A_h \sin(\omega_h t + \varphi_h) + \mu(t) \tag{1}$$

In Eq. (1), N = total number of harmonics, $\omega_h = h.2\pi f_0$ (f_0 = fundamental frequency), $\mu(t)$ = Additive noise. The discrete time version of the above equation can be written as

$$x(k) = \sum_{h=1}^{N} A_h \sin(\omega_h k T_s + \varphi_h) + \mu(k) \tag{2}$$

In Eq. (2), T_s = Sampling period. The parameters of the harmonics have been estimated from the discrete time signal. Let the estimated parameters be A'_h and φ'_h. The distorted signal with estimated parameters is represented as

$$x(k)' = \sum_{h=1}^{N} A'_h \sin(\omega_h k T_s + \varphi'_h) \tag{3}$$

For estimation of exact parameters, an error is evaluated using Eq. (4) given by

$$\text{Error}, d(k) = x(k) - x(k)' \tag{4}$$

The objective function is framed with the help of error signal to estimate the parameters of harmonic signal given by

$$J = \min \sum_{k=1}^{N} d(k)^2 \tag{5}$$

In this paper, the objective function is minimized to estimate accurate parameters of harmonics by the harmony search algorithm whose details are provided in below section.

3 Harmony Search (HS) Optimization Algorithm

Harmony search optimization (HS) is a population-based algorithm proposed by Geem from music improvisation concept [20–23]. The first step in this algorithm is to initialize the optimization process for the objective function $f(x_1, \ldots, x_n)$ with parameters such as range of variables $a_i \leq x_i \geq b_i, i = 1, 2, \ldots, n$, harmony memory (HM) vector size (HMS), harmony memory rate coefficient (HMRC) and pitch adjusting rate (PAR). Next is to initialize the vector of harmony memory (HM). For this, randomly pick HMS number of vectors $(x_1, \ldots, x_n)$ and put them in the HM vector corresponding to the dominant values $f(x_1, \ldots, x_n)$:

$$\text{HM} = \begin{bmatrix} x_1^1, \ldots, x_n^1 & | & f(x^1) \\ \vdots & | & \vdots \\ x_1^{\text{HMS}}, \ldots, x_n^{\text{HMS}} & | & f(x^{\text{HMS}}) \end{bmatrix}.$$

The next step is to update agents of HS $\boldsymbol{x}' = \boldsymbol{x}'_1, \ldots, \boldsymbol{x}'_n$. For each $i = 1, 2, \ldots, n$ the element x'_i is chosen. With the probability level to HMCR, from the total numbers x_i obtained in the vector of HM and with the probability level to 1—HMCR, randomly from the presumed limit $a_i \leq x_i \geq b_i$. If, in the prior step, the element x'_i is chosen from the vector of HM then, with the probability level to PAR, adjust the element x'_i in this way, $x'_i \rightarrow x'_i + \alpha$ (control the pitch of the note), for $\alpha = bw.u$, where bw indicates the bandwidth part of the limit of the variables and u is the randomly chosen number from range $\in [-1, 1]$ and with the probability level to 1—PAR we have nothing to do. If $f(x') < f(x^{\text{HMS}})$ then replace the element x' inside the vector of harmony memory HM instead of the element x^{HMS} and modify vector HM corresponding to the advancing values of the objective function. Updating HM vector steps are repeated until the termination criterion is satisfied.

4 Simulation Results

To analyze the performance of the harmony search algorithm for the estimation of harmonic parameters, two case studies with different signals have been taken.

Signal 1: Signal corrupted with noise along with DC component with decaying nature is considered as signal 1. In this case, a stationary signal having harmonics of order fundamental, 3rd, 5th, 7th, 11th is generated in MATLAB. The fundamental frequency (f_1) is 50 Hz, 3rd harmonic frequency $f_3 = 150$ Hz, 5th harmonic frequency $f_5 = 250$ Hz, 7th harmonic frequency $f_7 = 350$ Hz, eleventh harmonic frequency $f_{11} = 550$ Hz. The amplitude value of the fundamental harmonic component had taken a higher value compared to other harmonic components.

$$
\begin{aligned}
x(t) = {} & 1.5.\sin(\omega t + 80) + 0.5\sin(3\omega t + 60) \\
& + 0.2\sin(5\omega t + 45) + 0.15\sin(7\omega t + 36) \\
& + 0.1\sin(11\omega t + 30) + 0.5\exp(-5t) + \mu(t)
\end{aligned}
$$

where $\mu(t)$ = random noise (Tables 1, 2 and Fig. 1).

Signal 2: In this case, a stationary signal having harmonics of order fundamental, 3rd, 5th, 7th, 11th, is generated in MATLAB (Table 3).

$$
x(t) = 1.2\sin(2\pi f_1 t + 75) + 0.2\sin(2\pi f_3 t + 55)
$$

Table 1 Optimal amplitude values for signal-1obtained by HS

Technique	Quantity	Fundamental	3rd	5th	7th	11th	DC
PSO	Amplitude	1.5010	0.4996	0.2087	0.1496	0.1004	0.4984
HSO	Amplitude	1.5000	0.4994	0.2073	0.1503	0.1000	0.4989

Table 2 Optimal amplitude and phase values for signal-1 obtained by HS

Technique	Quantity	Fundamental	3rd	5th	7th	11th	DC
PSO	Amplitude	1.4897	0.5003	0.1946	0.1500	0.0998	0.5011
	Phase	77.9899	59.9691	48.6828	36.009	30.149	
HSO	Amplitude	1.5003	0.4994	0.1966	0.1504	0.1003	0.5011
	Phase	80.0028	60.0291	44.8954	36.077	29.930	

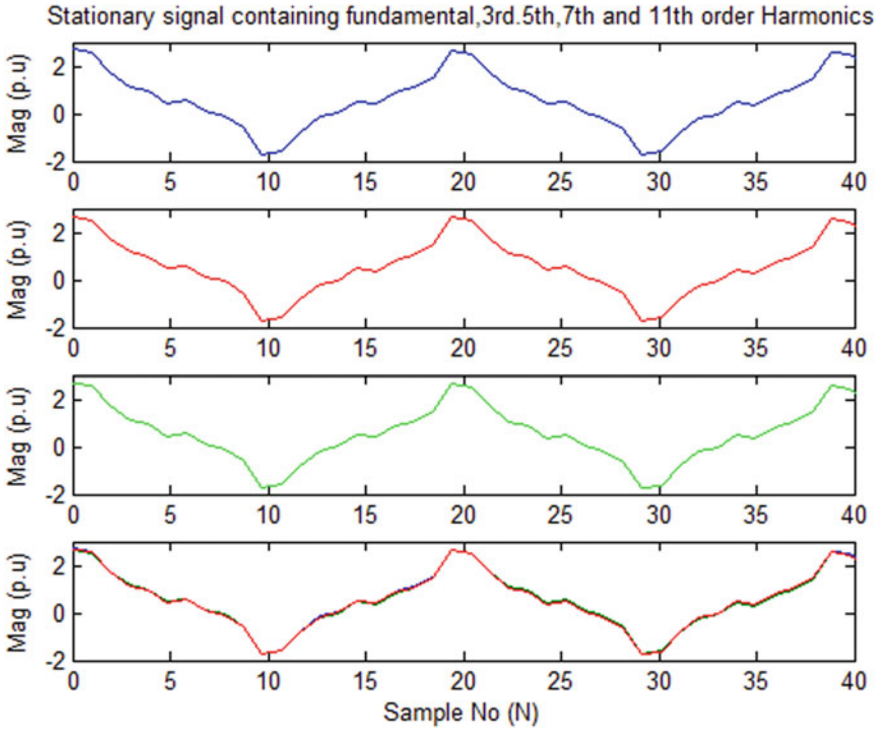

Fig. 1 Estimation plots of signal 1 using PSO and HS

Table 3 Optimal amplitude and phase values for signal-2 obtained by HS

Algorithm	Parameter	Fundamental	3rd	5th	7th	11th
PSO	Amplitude	1.2302	0.2001	0.1945	0.1397	0.0999
	Phase	74.9938	53.0311	44.9234	38.6918	29.8427
HSO	Amplitude	1.2002	0.19997	0.2001	0.1499	0.0999
	Phase	75.0168	55.0139	44.9839	39.9947	29.9692

$$+ 0.2\sin(2\pi f_5 t + 45) + 0.15\sin(2\pi f_7 t + 40)$$
$$+ 0.1\sin(2\pi f_{11} t + 30) + \mu(t)$$

5 Conclusions

In this paper, direct curve-based harmonic estimation concept is presented for distorted power system signals, and these harmonic components are accurately estimated using HS algorithm. This method provided direct amplitude and phase values of power system signals of different harmonic contents. The comparisons with PSO showcase the advantages of the HS in estimation.

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