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Power system harmonic estimation using biogeography hybridized recursive least square algorithm

Santosh Kumar Singh *, Nabangshu Sinha, Arup Kumar Goswami, Nidul Sinha

Electrical Engineering Department, National Institute of Technology Silchar, Assam, India

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ABSTRACT

This paper presents a new hybrid method based on biogeography-based optimization (BBO) and recursive least square (RLS) algorithms, called BBO–RLS, to solve harmonic estimation problem in case of time varying power signal in presence of different noises. BBO algorithm searches for the global optimum mainly through two steps: migration and mutation. The basic BBO algorithm is combined with RLS in an adaptive way to sequentially update the unknown parameters (weights) of the harmonic signal. Practical validation is also made with the experimentation of the algorithm with real time data obtained from a solar connected inverter system panel with power quality analyzer and estimation is performed under simulation. Comparison of the results achieved with the proposed algorithm demonstrates its superiority over other recently reported five algorithms like GA, PSO, BFO, F-BFO with Least Square (LS), and BFO–RLS in terms of accuracy, convergence and computational time.

Introduction

Accurate estimation and analysis of power system harmonic is essential to determine harmonic levels for effectively designing and mitigating filters, which reduces the harmonic levels from the signal [1]. The two parameters, such as amplitude and phase, are highly essential for designing the suitable filters for the elimination and reduction of harmonics and its effects in a power system. The harmonic signals produced in the power network are dynamic in nature. This nature of the harmonic signal calls for some fast methods for measuring and estimating harmonic signals [1,2].

In the past few decades, various approaches have been proposed to estimate the parameters of these harmonics [1,3]. The Fast Fourier Transform (FFT) is a suitable approach for stationary signal, but it loses accuracy under time varying frequency conditions and also posses picket and fence problems [4]. The International Electro-technical Commission (IEC) standards recommend utilization of DFT over a rectangular window of exactly 12 cycles for 60 Hz (10 cycles for 50 Hz) and frequency resolution of 5 Hz [3,4]. For harmonic estimation, the most widely used one is the fast executable algorithm derived from Discrete Fourier Transform (DFT) [4]. However, the DFT-based algorithms do not perform stably for systems with time varying frequency.

Besides, many hybrid approaches [11–15] based on integrating both digital signal processing and soft computing techniques, namely, Genetic Algorithm Least Square (GA-LS) [11], Particle swarm optimization least square (PSOPC-LS) [13], Fuzzy Bacteria foraging least square (FBFO-LS) [12] and Artificial bee colony least square (ABC-LS) [15] have been reported in the literature. In these hybrid schemes, the advantages of combining both least square and soft computing algorithms are to improve the convergence time and accuracy [15,16]. All of the heuristic algorithms have implicit parallelism and hence have better search capability. In this category of hybrid approaches, first the attempt has been made to optimize the phase by using metaheuristic algorithms of the harmonic components of the signal and then the conventional least square is applied to get the amplitude of the harmonic signal [14]. Such hybrid algorithms have shown encouraging performances in solving harmonic estimation problems essentially because the actual models of voltage and current signals are nonlinear in phase and linear in amplitude [14,15].

Another approach based on bacteria foraging optimization (BFO) [14] scheme is used for estimating the phase of fundamental and harmonic components, whereas, the conventional recursive least square (RLS) technique is used for estimating the amplitude of these components reported in [14].

Recently, a new meta-heuristic optimization concept, biogeography based optimization (BBO), based on biogeography was proposed by Simon [8–10] for optimizing various cost functions. Biogeography is the nature's way of distributing species. It is

* Corresponding author. Tel.: +91 9678845384; fax: +91 3842 224797.
E-mail address: santoshkrsingh.nits@gmail.com (S.K. Singh).

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Nomenclature

v_t	distorted voltage signal
H	harmonic order
ω_h	harmonic angular frequency
f_1	fundamental frequency
θ_h	phase of the harmonic signal
β_{dc}	DC decaying term
ε_t	additive noise
H_k	observation vector
θ_k	vector of unknown parameters (weight)
T_{Samp}	sampling time

modeled after the immigration and emigration of species between islands in search of more friendly habitats [8,9]. BBO is one of the newest EAs, and it has already proven itself as a valuable optimization technique compared to other already developed heuristic search techniques [5–7,8,9,17]. The Markov analysis by Simon et al. [8,9] proved that BBO outperforms the GA on simple and complex benchmark functions when used with low mutation rates. Simon [8,9] also reported experimental studies comparing BBO performance with many other EAs on a wide set of benchmarks. The results obtained from BBO are promising [10].

In view of the above, an urge is felt to investigate the performance of a new hybrid algorithm called BBO–RLS algorithm for the first time in which BBO algorithm is used for estimating the phase of the fundamental and harmonic components, whereas the conventional RLS technique is used for estimating the amplitude of these components of distorted power system signal. The comparative performance of the proposed algorithm is investigated with five other recently reported algorithms, such as GA-LS [11], PSO-LS [13], BFO [14], F-BFO-LS [12], and BFO–RLS [14], for fast and accurate estimation of harmonic, sub harmonic, inter harmonic in power system signals.

The main objectives of the present work reported in this paper are:

(a) Maiden application of Biogeography Based Optimization hybridized with Recursive Least Square (BBO–RLS) algorithm is proposed for estimating amplitudes and phases of the fundamental, harmonics, inter and sub harmonics in presence of various noises in power system signal.
(b) To evaluate the comparative performance of the proposed algorithm as compared to other hybrid algorithms like GA-LS [11], PSOPC-LS [13], BFO [14], F-BFO-LS [12], BFO–RLS [14] in finding the best harmonic estimator.
(c) To evaluate the performance of the algorithms for accurately estimating harmonic parameters on the data obtained from a real time industrial data setup for finding the best and appropriate method for harmonic estimation.

Biogeography

Biogeography describes the process of migration of species from one island to another along with arise and become extinct [8,9]. A habitat is an area that is geographically isolated from other areas. Areas, which are well suited as residences for biological species, are known to have a high habitat suitability index (*HSI*). Different factors that influence *HSI* include rainfall, diversity of vegetation, topographic features, land area, and temperature [8,9]. The variables that characterize habitability are called suitability index variables (*SIVs*). *SIVs* can be considered as the independent variables of the habitat, and *HSI* can be calculated using these variables. Habitats with a high *HSI* tend to have a large number of species, while those with a low *HSI* have a small number of species [8,9].

Migration of some species from one habitat to other habitat is known as emigration process. When some species enters into one habitat from any other outside habitat, it is known as immigration process [9]. Habitats with a high *HSI* have a low species immigration rate because they are already nearly saturated with species. Therefore, high *HIS* habitats are more static in their species distribution than low *HSI* habitats. By the same token, high *HSI* habitats have a high emigration rate. Habitats with a low *HSI* have a high species immigration rate because of their sparse populations. This immigration of new species to low *HSI* habitats may raise the *HSI* of that habitat, because the suitability of a habitat is proportional to its biological diversity [9]. For details about the BBO algorithm the readers are referred to [8,9].

Harmonic estimation problem formulation

The nonlinearity that arises in the sinusoidal model is due to the phase of the sinusoids. In this paper, Biogeography Based Optimization (BBO) algorithm is used for the optimizing the unknown parameters (weights) for the estimation and these optimized unknown parameters are considered as the input of the RLS algorithm for finding the amplitudes and also for updating weights [14].

Mathematical modeling of harmonics

A distorted voltage signal can be modeled as the sum of higher order harmonics of unknown magnitudes and phases and can be represented as (1).

$$v_t = \sum_{h=1}^{H} v_h Sin(\omega_h t + \theta_h) + v_{dc}\exp(-\beta_{dc} t) + \varepsilon_t \tag{1}$$

where $\omega_h = h \times 2\pi f_1$ $h = 1, 2, \ldots, H$

So, the discrete time version of (1) can be represented as (2)

$$v_k = \sum_{h=1}^{H} v_h Sin(\omega_h k T_{Samp} + \theta_h) + v_{dc}\exp(-\beta_{dc} k T_{Samp}) + \varepsilon_k \tag{2}$$

Now, using the first two terms of the Taylor series and also neglecting higher order terms, the decayed part of the signal can be approximated as:

$$v_{dc}\exp(-\beta_{dc} k T_{Samp}) = v_{dc} - v_{dc}\beta_{dc} k T_{Samp} \tag{3}$$

Substituting (3) in (2), (3) becomes

$$v_k = \sum_{h=1}^{H} v_h Sin(\omega_h k T_{Samp} + \theta_h) + v_{dc} - v_{dc}\beta_{dc} k T_{Samp} + \varepsilon_k \tag{4}$$

So, this signal can be written in the form as (5)

$$v_k = \sum_{h=1}^{H} \begin{bmatrix} v_h \sin(\omega_h k T_{Samp})\cos\theta_h + v_h \cos(\omega_h k T_{Samp})\sin\theta_h \\ + v_{dc} - v_{dc}\beta_{dc} k T_{Samp} + \varepsilon_k \end{bmatrix} \tag{5}$$

Hence, for the purpose of estimation of the harmonic parameters, this signal can be written in the parametric form as:

$$v_k = H_k \theta_k \tag{6}$$