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Robust estimation of power system harmonics using a hybrid firefly based recursive least square algorithm

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A B S T R A C T

This paper presents a new and hybrid algorithm based on Firefly Algorithm (FA) and Recursive Least Square (RLS) for power system harmonic estimation. The hybrid FA–RLS algorithm is developed for estimating harmonics, inter harmonics and sub harmonics from a distorted and noise corrupted power signal. The basic strategy of the proposed algorithm is to integrate FA for getting the optimum initial weights for RLS algorithm that sequentially updates the unknown parameters (weights) of the harmonic signal. Simulation and practical validation is made with experimentation of the algorithms with real time data obtained from a solar connected inverter system. Comparison of results amongst recently proposed Artificial Bee Colony Least Square (ABC–LS), Bacteria Foraging Optimized Recursive Least Square (BFO–RLS) and FA–RLS algorithms reveals that proposed FA–RLS algorithm is the best in terms of accuracy, convergence and computational time.

Introduction

The regular and significant use of the power electronics and solid-state devices in recent years has led to increase the harmonic pollution levels in power system signal. The increasing power demands upon various electrical resources have made power quality an important issue for modern electric utility and power system operation. The variety of negative impacts of harmonics based on electrical voltages and currents such as increase of core (I^2R) losses, signal interference, over voltages, data loss and circuit breaker failure, as well as equipment heating, malfunction, damage of the devices, rotor heating, pulsating output torque, excessive motor heating, inefficiency of the equipments and also causes the reduction of the lifespan of sensitive equipments has prompted to establish a number of standards and guidelines regarding acceptable harmonic levels [1,2,10,11,17,18,20,21].

In the past few decades, various approaches have been proposed to estimate the parameters of these harmonics [1,2,11,17]. The Fast Fourier Transform (FFT) is a suitable approach for stationary signal, but it loses accuracy under time varying dynamic condition of the power signal and also posses picket and fence problems. The International Electro-technical Commission (IEC) standard drafts have specified signal processing recommendations and definitions for harmonic, sub-harmonic and inter-harmonic measurement [3,4]. These recommendations utilize DFT over a rectangular window of exactly 12 cycles for 60 Hz (10 cycles for 50 Hz) and frequency resolution of 5 Hz [3]. For harmonics, the most widely used one is the fast executable algorithm derived from Discrete Fourier Transform (DFT) [5]. However, the DFT based algorithms do not perform stably for systems with dynamic changes.

Apart from FFT and DFT, there are many improved algorithms such as Kalman Filter (KF), Prony Based Methods, Enhanced Phase Locked Loop (EPLL) methods reported in the literature for solving harmonic estimation problems [1,2,10]. But each of the algorithms has several limitations in presence of noise in the signal. To overcome the limitations of the reported methods, this problem calls to develop more and more efficient methods which can accurately estimate harmonics from power system signals in presence of noise.

Besides, many hybridized algorithms based on integrating both digital signal processing and soft computing techniques, namely Genetic Algorithm Least Square (GA–LS) [6], Fuzzy Bacteria foraging least square (FBFO–LS) [7], Particle swarm optimization least square (PSOPC–LS) [8] and Artificial Bee Colony Least Square (ABC–LS) [12] has been reported in the literature. In these hybrid schemes, the advantages of combining the least square and soft computing algorithms are to improve the convergence time and accuracy. But all of the heuristic algorithms are population based search algorithms, which work with a population of strings that represent different potential solutions [12,13]. Therefore, each of them has some issues related to parallelism that enhances the

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Nomenclature

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

searching capability and the optima can be located more quickly when applied to complex optimization problems. In this category of hybridized approaches, first the attempt has been made to optimize the phase by using a meta heuristic algorithm of the harmonic components and then the conventional Least Square (LS) is applied to get the amplitude of the harmonic signal [12,13]. 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.

Further, another approach based on Bacteria Foraging Optimization (BFO) scheme [7,13] 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 [13]. The hybrid BFO–RLS approach used as phase estimator based on the constant run length, which is the height by which the bacteria will climb or tumble in one go for foraging strategy fails to provide the optimal result. Therefore, in this paper, run length is made adaptable through a Takagi–Sugeno fuzzy scheme based upon the minimum value of cost function [13].

Furthermore, according to recent bibliography, the Firefly Algorithm (FA) [14–16] is reported to be very efficient and outperform other conventional algorithms, such as GA, PSO, ABC and BFO algorithms for solving many optimization problems; a fact that has been justified in a recent research, where the statistical performance of the firefly algorithm was measured against other well known optimization algorithms using various standard stochastic test functions [14–16]. Its main advantage is the fact that it uses mainly real random numbers and it is based on the global communication among the swarming particles (i.e., the fireflies) and as a result, it seems to be more effective in multi modal optimization problems, such as the fundamental and harmonic estimation problem in our case.

In the view of the above following are the main objectives of the present work.

(a) Maiden application of hybridized FA–RLS algorithm 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 recently reported hybrid algorithms like ABC–LS [12] and BFO–RLS [13] for 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 setup for finding the best and appropriate method for harmonic estimation.

Firefly algorithm

The Firefly Algorithm (FA) developed by Dr. Xin-She Yang, is a meta heuristic, nature-inspired, optimization algorithm which is based on the flashing behavior of fireflies [14]. FA algorithm is based on the swarming behaviors of fishes, insects, or bird schooling in nature. In particular, although the firefly algorithm has many similarities with other algorithms which are based on the so called swarm intelligence, such as the Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC), and Bacterial Foraging Optimization (BFO) algorithms, it is indeed much simpler both in concept and implementation [14–16]. Furthermore, according to recent bibliography, the FA algorithm is very efficient and can outperform other algorithms, such as GA, PSO and BFO for solving many optimization problems. Further a fact has been justified in a recent research, where the statistical performance of the FA was measured against other well known optimization algorithms using various standard stochastic test functions [16]. Its main advantage is the fact that it uses mainly real random numbers, and it is based on the global communication among the swarming particles (i.e., the fireflies, and as a result, it seems more effective in single and multi objective optimization problems such as the harmonic estimation in our case.

The FA has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies [15,16]. These are the following: (1) all fireflies are unisex, and they will move toward more attractive and brighter ones regardless their sex. (2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly (3). The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem.

Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function in (1).

$$\beta(r) = \beta_0 \exp(-\gamma r^m), \quad m \geqslant 1 \tag{1}$$

where r is the distance between any two fireflies, β_0 is the initial attractiveness at $r = 0$, and γ is an absorption coefficient which controls the decrease of the light intensity.

Distance

The distance between any two fireflies i and j, at positions x_i and x_j, respectively, can be defined as a Cartesian or Euclidean distance as follows (2) and (3).

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \tag{2}$$

where $x_{i,k}$ is the kth component of the spatial coordinate x_i of the ith firefly and d is the number of dimensions,

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{3}$$