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An artificial bee colony-least square algorithm for solving harmonic estimation problems

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ABSTRACT

Solving harmonic estimation problems in power quality signals has attained significant importance in recent times. Stochastic optimization algorithms have been successfully employed to determine magnitude of this information in an unknown signal contaminated with noise or containing additive dc decaying components. The present paper shows how a recently proposed stochastic optimization algorithm, called artificial bee colony algorithm, can be hybridized with least square algorithm to solve these problems effectively. The proposed algorithm has been tested for a series of case studies employing different benchmark environment situations and our extensive simulation tests validate the usefulness of the proposed algorithm and it could largely outperform several competing simulation algorithms, proposed in the recent past. The effectiveness of the proposed algorithm is further demonstrated for those situations where the number of harmonics present in the signal is also not known, along with the magnitude and phase of each harmonic.

1. Introduction

In recent times with significant progress in industrial scenario, the use of power electronic equipments have been increased manifold. With the increased use of converter-driven equipments (from consumer electronics to computers, adjustable speed drives etc.), these sophistications have also led to increasingly unwanted situations of significant growth in voltage waveform distortions. Due to the nonlinear characteristics of these equipments, the power system suffers from serious harmonic pollution. Besides, saturation of transformer core, generation of magnetic inrush current because of switching of transformer, etc. are the possible causes of generation of harmonics. Due to the asymmetrical nature of the magnetizing inrush current, even harmonics (in particular the second harmonic) appear to be the dominant ones in the harmonic spectrum [1]. Similarly, occurrence of faults in a power system, installation of capacitor bank in utility distribution system or in industrial power system can cause harmonic problems [2,3]. This harmonic pollution may cause several ill effects like worsening of power quality for end users, incurrence of greater loss in transmission lines, overheating of machines, malfunctioning of relays and breakers, etc.

Harmonic studies play an important role in characterizing and understanding the extent of the harmonic problem. It includes estimation of parameters of the harmonics such as the amplitudes and phases, etc. This estimated information can be possibly advantageously used to compensate the harmonic components, by injecting suitable corresponding quantities in the power system. The content of frequency, their amplitudes and phases etc. depend on the nature of waveforms present which in turn, depend on the sources of harmonics or the causes of harmonics.

So far, several research works have been reported in the literature to perform useful investigations on harmonic analysis. The most widely used computational algorithm for harmonic analysis, known so far, is the fast Fourier transform (FFT) [4,5,19]. However, because of certain restrictions (aliasing, leakage, and picket fence phenomena) the FFT algorithms cannot compute the results accurately under certain undesirable conditions. In [6,7,20,21], an alternate approach was proposed utilizing a simple, linear and robust Kalman filtering approach. A frequency and phasor estimating algorithm using finite impulse response (FIR) filter and the concept of using a correction factor in this regard (called combine method or CM) was proposed in [8]. It was shown that this approach could overcome the shortcomings and eliminates the pitfalls present in FFT algorithm. In recent times, several new algorithms have been reported hybridizing a stochastic optimization algorithm, e.g. genetic algorithm (GA) inspired by the Darwinian law of survival of the fittest [9], particle swarm optimization (PSO) algorithm inspired by the social behavior of bird flocking or fish schooling [10], and fuzzy bacterial foraging (FBF) optimization algorithm inspired by Takagi–Sugeno fuzzy rule applied on intelligent

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foraging behavior of *E. coli* bacteria [11,22], with least square (LS) strategy to solve this problem. These algorithms essentially utilize the evolutionary optimization technique for phase estimation and the LS based approach for amplitude estimation. Such hybrid methods have shown encouraging performances in solving this category of problems essentially because the actual models of voltage and current signals are nonlinear in phase and linear in amplitude.

In the present work, a new swarm intelligence computation based technique, called artificial bee colony (ABC) is used for estimating the phase of the fundamental and harmonic components, whereas the conventional LS technique is used for estimating the amplitude of these components. The ABC algorithm, which is one of the most recently introduced optimization algorithms, simulates the intelligent foraging behavior of a honey bee swarm and has been successfully employed in solving several engineering problems [13,14,23,24]. ABC broadly falls within the class of metaheuristic optimization based techniques that has been successfully employed to solve several other engineering problems which include prominent evolutionary optimization based algorithms like genetic algorithm (GA) [25–27], evolutionary strategies (ES), genetic programming (GP), differential evolution (DE) [31,32], etc. swarm intelligence based techniques like particle swarm optimization (PSO) [28–30,39,40], ant colony optimization (ACO), etc., foraging and social behavior based algorithms like bacterial foraging optimization (BFO) [33–36], biogeography based optimization (BBO) [37,38], honey bee mating optimization algorithm, etc. It has been shown as a rich, early promise, simple and robust population based optimization algorithm in solving several nonlinear optimization algorithms. The performance of the proposed algorithm is compared vis-à-vis several other competing algorithms e.g. FFT, PSO, GA and FBF based algorithms for estimating the power system harmonics, utilized for several benchmark case study problems. The competing algorithms proposed before were used to solve the harmonic estimation problem considering that the number of harmonics is known a priori and those algorithms were used to determine the amplitudes and phases of these harmonics. In addition to these, the present work has been efficiently employed to solve those harmonic estimation problems, where even the number of harmonics present in the signal is considered to be unknown. It has been used for several other case studies in those situations. The simulation results show that, overall, the performance of the proposed ABC–LS combined algorithm is significantly better than the above mentioned competing algorithms and hence it can be efficiently employed to solve such engineering problems with high dimensionality.

The rest of the manuscript is organized as follows. Section 2 introduces the ABC algorithm in detail. Section 3 introduces how the harmonic estimation problem can be solved using ABC–LS combine algorithm. Section 4 presents the performance evaluations for extensive simulation case studies carried out. Section 5 presents the discussion and conclusion.

2. The artificial bee colony algorithm

The artificial bee colony (ABC) algorithm is a swarm based meta-heuristic algorithm which was introduced by Karaboga in 2005 for optimizing high dimensional numerical problems [12]. It was inspired by the intelligent foraging behavior of honey bees. The minimal model of forage selection that leads to the emergence of collective intelligence of honey bee swarms consists of three essential components: food sources, employed foragers and unemployed foragers, and defines two leading modes of the behavior: recruitment to a nectar source and abandonment of a source [13,14]. The exchange of information among bees is the most important phenomenon in the formation of collective knowledge. While examining the entire hive, it is possible to identify some parts that commonly exist in all hives. The most important part of the hive with respect to exchanging information is the dancing area. The communication among bees related to the quality of food sources occurs in the dancing area. The related dance is called the waggle dance. Since information about all the current rich sources is available to an onlooker bee on the dance floor, she probably can watch numerous dances and choose to employ herself at the most profitable source. There is a greater probability of onlookers choosing more profitable sources since more information is circulating about the more profitable sources. Employed foragers share their information with a probability, which is proportional to the profitability of the food source, and the sharing of this information through waggle dancing is longer in duration. Hence, the recruitment is proportional to profitability of a food source [14].

In ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources. The employed bee of an abandoned food source becomes a scout.

Similar to the other population-based algorithms, ABC is an iterative process. The search carried out by the artificial bees can be summarized by a number of actions as initialization of the population, initialization of the bee phase, calculating probability values involved in probabilistic selection, onlooker bee phase, scout bee phase [18].

In the first step, the ABC generates a randomly distributed initial population of NP solutions using the following equation

$$\phi_{ij} = l_j + rand(0, 1) \times (u_j - l_j) \quad (1)$$

where $i = \{1, 2, ..., NP\}$ and $j = \{1, 2, ..., D\}$, l_j and u_j are the lower and upper bound of the solution variable φ_{ij}, respectively, *NP* is the size of population, and *D* is the number of optimization variables.

After initialization, the population of the solutions is subjected to repeated cycles, $C = 1, 2, ..., MCN$ (*maximum cycle number*), of the search process of the employed bees, the onlooker bees and scout bees. An artificial employed or onlooker bee probabilistically produces a modification of the solution in her memory for finding a new food source and evaluates the nectar amount (fitness value) of the new source (new solution).

After all employed bees complete the search process, they share the nectar information of the food sources (solutions) and their position information with the onlooker bees on the dance area. An onlooker bee evaluates the nectar information acquired from all employed bees and chooses a food source with a probability related to its nectar amount. If this evaluation shows that its nectar is higher than that of the previous one, the bee memorizes the new position and forgets the old one. This probabilistic selection depends on the fitness values of the solutions in the population. A fitness- based selection scheme might be a roulette wheel, ranking based, stochastic universal sampling, tournament selection or another selection scheme. In basic ABC, roulette wheel selection scheme in which each slice is proportional in size to the fitness value is employed as follows

$$P_i = \frac{fit_i}{\sum_{i=1}^{NP} fit_i} \quad (2)$$

where fit_i is the fitness value of the solution *i* evaluated by its employed bee. This is proportional to the nectar amount of the food source (J_i or fit_i) in the position *i*. In this way, the employed bees exchange their information with the onlookers. In order to produce a new candidate food position from the old one, a greedy selection