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Full Length Article

Gravity Search Algorithm hybridized Recursive Least Square method for power system harmonic estimation

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ABSTRACT

This paper presents a new hybrid method based on Gravity Search Algorithm (GSA) and Recursive Least Square (RLS), known as GSA-RLS, to solve the harmonic estimation problems in the case of time varying power signals in presence of different noises. GSA is based on the Newton's law of gravity and mass interactions. In the proposed method, the searcher agents are a collection of masses that interact with each other using Newton's laws of gravity and motion. The basic GSA algorithm strategy is combined with RLS algorithm sequentially in an adaptive way to update the unknown parameters (weights) of the harmonic signal. Simulation and practical validation are made with the experimentation of the proposed algorithm with real time data obtained from a heavy paper industry. A comparative performance of the proposed algorithm is evaluated with other recently reported algorithms like, Differential Evolution (DE), Particle Swarm Optimization (PSO), Bacteria Foraging Optimization (BFO), Fuzzy-BFO (F-BFO) hybridized with Least Square (LS) and BFO hybridized with RLS algorithm, which reveals that the proposed GSA-RLS algorithm is the best in terms of accuracy, convergence and computational time.

1. Introduction

Harmonic estimation is the prime step in mitigating the most prominent problems of power quality in the power system. The various negative impacts of harmonic pollution in electrical network include – increase of I^2R losses for whole power network, various signal interferences, over and under voltages, loss of information and data, failure of circuit breaker operation, equipment heating, malfunction in the devices including damage, motor heating, pulsating and varying output torque, inefficiency and reduction in longitivity of the electrical appliances. The various impacts of harmonics have prompted to establish a number of suitable standards and proper guidelines regarding acceptable harmonic levels [1,2].

Accurate estimation and analysis of power system harmonic is essential to determine harmonic levels for effectively designing filters for mitigation of harmonics by way of removing the harmonic levels from the signal [2]. So from this point of view, it is highly imperative to know the quality of power delivered along with harmonic parameters, such as amplitude and phase[2–5]. These two parameters are highly essential for designing the suitable filters for the elimination and reduction of harmonics and their effects in 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 of measuring and estimating harmonic signals [1,2].

Some works are reported in the literature to address this problem wherein various approaches have been proposed to estimate the parameters of harmonics [1,2]. The Fast Fourier Transform (FFT) is considered as a suitable approach for stationary signal, but it suffers from loss of accuracy under time varying frequency conditions and posses picket and fence problems. The International Electrotechnical Commission (IEC) standard drafts has specified signal processing recommendations and definitions for harmonic, sub-harmonic and inter-harmonic measurement [1–3].

So far the hybrid approaches are concerned, significant contributions are reported in the literature under Refs. [6–10]. All these approaches are 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 with passive congregation-least square (PSOPC-LS) [8] and Artificial bee colony-least square

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Nomenclature

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

(ABC-LS) [9]. In these hybrid approaches, the prime objectives of combining both least square and soft computing algorithms are to improve the convergence and accuracy of the harmonic estimation method. All of the heuristic algorithms are based on population search algorithms, and work with a population of strings representing different potential solutions [9]. Therefore, each of them has implicit parallelism that enhances their search capability and the optimum can be located more quickly when they are applied to complex optimization problems [10]. In this category of hybrid approaches, first the attempt has been made to optimize the phase of the harmonic components of the power signal by using metaheuristic algorithms and then the conventional recursive least squares are applied to get the amplitude of the harmonic signal [10]. 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 [10].

Another hybrid approach [10] based on bacteria foraging optimization (BFO) is reported in which the phases of the fundamental and harmonic components are estimated using BFO, whereas, the conventional recursive least square (RLS) technique is used for estimating the amplitude of these components.

Gravitational Search Algorithm (GSA) is a recently reported algorithm that has been inspired by the Newtonian's law of gravity and motion. Since its introduction in 2009, GSA has undergone a lot of changes to the algorithm itself and has been applied in various applications [11]. At present, there are various variants of GSA such as Chaotic GSA incorporated to use sequences generated from chaotic systems to substitute random numbers for different parameters of GSA where it is necessary to make a random-based choice and another variant of chaotic is incorporated to utilize the chaotic search as a local search procedure of GSA. Oppositional GSA is developed to enhance and improve the original version of GSA. The original GSA is chosen as a parent algorithm and opposition-based ideas are embedded in it with an intention to exhibit accelerated convergence profile [12–15].

In GSA algorithm the different agents are considered as the objects and their performance is measured by their masses. All these objects attract each other by the gravity force and this force causes a global movement of all objects towards the objects with heavier masses [12,13]. Hence, masses cooperate using a direct form of communication through gravitational force. The heavy masses, which correspond to good solutions, move more slowly than lighter ones, which in turn guarantee the exploitation step of the algorithm [12,13]. In GSA, each mass (agent) has four specifications namely position, inertial mass, active gravitational mass, and passive gravitational mass [11]. The different positions of the masses correspond to a solution of the problem, and its gravitational and inertial masses are determined using a fitness function. Basically, each mass presents a solution, and the algorithm is navigated by properly adjusting the gravitational and inertia masses [11]. As the time passes, it is expected that the masses will be attracted by the heaviest mass. This heaviest mass will be the optimum solution in the search space [12,13]. GSA is considered as one of the newest Evolutionary Algorithm (EA) and it has already proved itself as a very competent optimization technique in comparison to other developed heuristic optimization techniques [12,13] in terms of faster convergence, higher capability to escape from local optima and better quality of solutions.

The estimation of harmonics is carried out in two phases; first the phases of the fundamental and other harmonic components are to be obtained as optimal weights using a nonlinear optimization algorithm and then their amplitudes are to be computed using recursive least square algorithm. The non-linearity arises due to the phases of the harmonic signals. To add further the time varying dynamic signal in presence of noise make this problem more non-linear and likely to have more local optima which makes it an appropriate field of application of heuristic search algorithms. Also, the estimation of amplitudes is more of linear one calling for conventional recursive least square algorithms. Hence, an urge is felt to consider the GSA algorithm for estimating the phases of the fundamental and other harmonic components, while their amplitudes are estimated by using the RLS algorithm to enhance the convergence as well as the accuracy of the estimation algorithm.

Motivation: Every population based algorithm uses two search processes: exploration for more of global best and exploitation mostly for local best. This algorithm uses exploration capability at the beginning to escape local optimum problems followed by more exploitation at later generations. A time function, named as K_{best} particle/agent, is used to attract other particles. The performance of GSA is improved by controlling exploration and exploitation. The value of K_{best} function decreases with time linearly and at last only one agent will be there with heavy mass that represents the global solution [12,15–17].

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

(a) Maiden application of Gravity Search Algorithm (GSA) based Recursive Least Square (GSA-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 [6,10], PSOPC-LS [8,10], BFO [7,10], F-BFO-LS [7,10], BFO-RLS [10] 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.

2. Gravitational Search Algorithm (GSA)

The GSA algorithm can be considered as an isolated system of masses based on the Newtonian laws of gravitation and motion [11,12].