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Neuro-evolutionary approaches to power system harmonics estimation

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A R T I C L E I N F O

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This paper focuses on exploiting two computational intelligence techniques such as artificial neural network and evolutionary computation techniques in estimation of harmonics in power system. Accurate estimation of harmonics in distorted power system current/voltage signal is essential to effectively design filters for eliminating harmonics. No standard design is available for handling of local minima and training of NN but Evolutionary Computation (EC) techniques are capable of resolving local minima. Neural Network and Evolutionary Computing (Bacterial Foraging Optimization (BFO)) are combined to achieve accurate estimation of different harmonics components of a distorted power system signal. First estimation of unknown parameters are carried out using BFO, then optimized output of BFO are taken as initial values of the unknown parameters for Adaline. Amplitude and phase of fundamental and harmonics components are determined from final updated values of unknown parameters using Adaline. This Adaline based Bacterial Foraging Optimization (Adaline-BFO) hybrid estimation algorithm addresses the problems of slow convergence and reduction of time generation of off-springs happening in Genetic Algorithm (GA), and to avoid local minima in Particle Swarm Optimization (PSO). The proposed Adaline-BFO algorithm has been applied for estimation of harmonics of the voltage obtained across the inverter terminals of a prototype Photovoltaic (PV) system. From the obtained results, it is confirmed that the proposed Adaline-BFO algorithm provides superior estimation performance in terms of improvement in % error in estimation, processing time in computation and performance in presence of inter and sub-harmonic components when compared with the Discrete Fourier Transform (DFT), Kalman Filter (KF) and BFO algorithms.

Introduction

Voltage and current waveforms in an AC power system are expected to be sinusoidal with constant amplitude and frequency. However, almost all power plant components possess the undesirable property of introducing distortion into AC power system causing the voltage and current waveforms to deviate from their sinusoidal waveforms. As a matter of fact, voltage and currents possess a set of sinusoidal waveforms of varying amplitudes and phase having frequencies that are integer multiples of fundamental frequency. These frequency multiples of the fundamental frequency are called harmonic frequencies. Due to the significant growth of the solid-state power switching devices in recent years, there is corresponding increase in harmonic levels in power systems. Further, excessive usage of nonlinear loads such as power electronics devices introduces significant amounts of harmonics into power system. Power converters used in variable-speed drives, power supplies and uninterruptible power supply (UPS) systems are responsible for a disproportionate amount of harmonics troubling power systems now-days. Arc furnace is another significant source of harmonics.

As discussed in the earlier paragraph, power system voltage or current signal deviates from pure sinusoidal waveform and in particular the distortion of the current waveform becomes more complex as shown in Fig. 1.

If suitable filtering is not undertaken then these devices will introduce inter-harmonics (having frequencies non-integer multiple of fundamental but more than fundamental frequency) and sub-harmonic ((having frequencies non-integer multiple of fundamental but less than fundamental frequency) components into the power system. Both harmonics and interharmonics have adverse effects such as increased I^2R losses, over voltage, unbalancing and mal-operations of the relays and saturation of transformer core. It is pertinent that accurate estimation of harmonics in distorted power system current/voltage signal is essential to effectively design filters for eliminating harmonics. Since measurement of power system harmonics in presence of noise, dc decaying component, inter-harmonics, sub-harmonics and dynamic changes in

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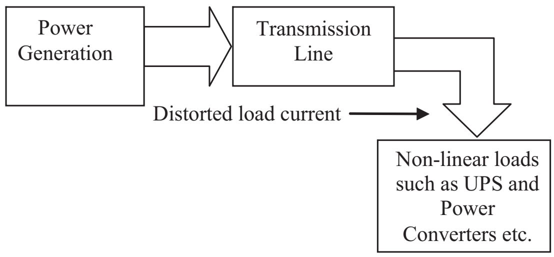

Fig.1. Schematic of harmonics estimation problem.

signal may give rise to erroneous results estimation techniques are employed to mitigate harmonics from the distorted signals. Hence, the harmonics estimation problem is intended to develop accurate estimation algorithms for obtaining amplitude and phase of the harmonics of the distorted voltage/current signal.

From the literature [1,2], it is found that several techniques have been employed to evaluate the harmonics. Out of which the Fast Fourier Transform (FFT) is widely used because of its faster computational capability [1,2]. Other algorithms include recursive Discrete Fourier Transform (DFT), digital differentiator based method [3], spectral observer and Hartley transform as a means of harmonic extraction. The most commonly used technique for parameter estimation is Least Square (LS) and Recursive Least Square (RLS) algorithms [4,5].RLS is used extensively for estimating frequency contents on-line. Kalman filtering technique uses a simple, linear and robust algorithm to estimate the magnitude of the known harmonics embedded in the signal along with stochastic noise [6,7]. It gives a better noise rejection and estimation compared to FFT algorithms [1]. But the dynamics involved in KF raises concern since it exhibits poor performance with respect to sudden change in amplitude, phase or frequency of signal.

Joorabian et al. [8] decomposed the total harmonics estimation problem into a linear and non-linear problem. A linear estimator (Least Square (LS)) has been employed for amplitude estimation and an adaptive linear combiner "Adaline" which is very fast and has been employed for harmonics phase estimation. It is observed that improvements in convergence and processing time are achieved using this algorithm. This algorithm provide correct estimates for both static, dynamic and fault signal, but estimation of harmonics for inter and sub harmonic components has not been attempted. Lai et al. [9] combined the Least Square technique with artificial neural networks (NNs) for harmonic extraction in time varying situations. This method is capable of dealing simultaneously the measurement of varying frequency, amplitude and any harmonic components present in the power system. There is no restriction about evaluation of the number of harmonic component excepting increasing complexity of neural network as the number of harmonics components is increased. Mori et al. [10] presented a method based on back propagation learning for feed-forward neural network for harmonics estimation. For the effectiveness of the proposed method, it has been applied to the voltage harmonics [11] observed through a computer based measurement system and its performance has been compared with different conventional methods. A neural network based algorithm has been developed in [12] to estimate both magnitude and phase up to eleventh harmonics (550 Hz) of a power system. They used a method for determination of model parameters involving the noise environment. Estimation performance of the neural method is also compared with that of a conventional DFT method. This comparison says that NN approaches yields fast response and high accuracy compared to DFT and the method is also validated by experimental results. Discrete Wavelet Transform [13] is also popularly used for detection and classification of power quality disturbances.

The contributions of the paper include development of a new Adaline-BFO approach to power system harmonics estimation that gives improvement in estimation performance. Performance of the proposed hybrid technique is compared with that of DFT, Kalman Filter and BFO algorithm.

The paper is organized as follows. Section 2 brief about the problem statement of the paper. Section 3 describes the proposed Adaline–BFO hybrid estimation scheme for harmonics estimation. Section 4 presents simulation studies on some existing methods such as DFT, KF and BFO together with the proposed Adaline-BFO approach for harmonics estimation applied to distorted power signals. Section 4 also describes the experimental set-up developed to validate the efficacy of the proposed algorithm. Section 5 concludes the paper.

Problem statement

An estimation problem can be posed as an optimization problem. Consider Fig. 2, which shows the parameter estimation problem for a power system, where the optimization needs to be performed for example, by using Evolutionary Computation (EC) approaches such as PSO, BFO [17] in view of the global optimum characteristics or through a hybrid algorithm involving neural and EC techniques in view of benefiting their individual characteristics in achieving global parameter estimation.

In Fig. 2, power system is treated as a plant, when input is fed to the plant, then the output obtained is the desired output. When same input is fed to a model, then output obtained is the estimated output. These desired and estimated output are compared, the error so obtained is minimized through hybrid optimization algorithm.

The optimization task in Fig. 2 can be accomplished by employing any classical optimization techniques but to achieve global optimization, it is intended to develop a hybrid algorithm involving Neural Network (NN) and EC techniques. It may be noted that EC techniques such as GA [16], BFO and PSO are suitable candidates for updatation of NN using global optimum features.

BFO rests on a simple principle of the foraging (food searching) behavior of E.Coli bacteria in human intestine. BFO also outperforms many powerful optimization algorithms in terms of convergence speed and accuracy. Adaline network [14,15] is used to update the weights of NNs adaptively so that the estimated value converges to the desired value (generated synthetic signal/experimental signal).

The instrumentation of the distorted power signal is accomplished through an experimental set-up involving a DC–DC converter, an inverter and a FPGA with Data acquisition system. The improvements in estimation performances are achievement in

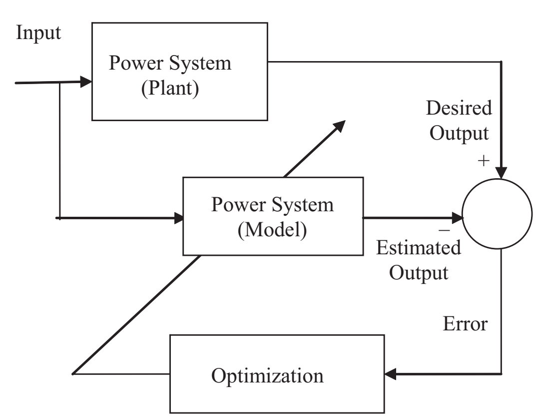

Fig. 2. Power system estimation as an optimization problem.