Shuffled Frog-Leaping Algorithm for Control of Selective and Total Harmonic Distortion

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ABSTRACT
The main purpose of active-filter based power-quality improvement problems is to reduce the total harmonic distortion (THD) and improve power factor (PF) as much as possible. However according to standards such as IEEE-519/IEC 61000, selective harmonic distortion (SHD) should be controlled. The conventional power factor correction techniques, assume the voltage source to be purely sinusoidal. But it is rarely true because nonlinear loads draw nonsinusoidal current from the source and that causes a nonsinusoidal voltage supply applied to the load. Under such conditions, any attempt to make the power factor unity by usual methods will result into a nonsinusoidal current, which increases total harmonic distortion (THD). On the other hand, harmonic free current does not necessarily result in unity power factor because of harmonics present in the voltage. Therefore, there is a trade-off between improvement in power factor and reduction of THD. One of the best solutions for this trade-off is to optimize PF while keeping THD and SHD into their prespecified limits. In this paper five methods including shuffled frog-leaping algorithm (SFL), conventional PSO (C-PSO), linearly decreasing inertia PSO (LDI-PSO), type 1 PSO (T1-PSO) and constant inertia PSO (CI-PSO) are employed in order to optimize PF while restricting the THD and SHD within the inertia constant. In this work, the compensating current to be supplied by the shunt active power filter to the power system with these five optimization methods is applied and is observed using these evolution methods, PF has been improved considering all conditions. Also simulation results of a case study illustrate the high quality performance of SFLA among the algorithms used.

Keywords: THD, shuffled frog-leaping, SHD, power quality.

1. Introduction

In the last few years, power electronic technologies have been developed extensively for various applications such as lighting, adjustable speed drivers, and uninterruptible power supply systems as consequence of advanced use of semiconductor devices. This power electronics equipment draws nonsinusoidal current and result harmonic distortion. In a power system, the harmonic distortion can be caused by the active and passive nonlinear devices. Nowadays, most harmonic distortion is generated by the input stage of (active) electronic power converters. Due to the nonlinear structure, most power electronics equipment draws nonsinusoidal current, and thus, results in significant harmonic distortion in the power system has severely deteriorated the power quality (PQ) in electrical power networks. Power quality has become a significant factor when differentiating between successful utilities in the power network specially deregulated environment [1]. Harmonic analysis is an important application to power systems as an efficient approach to evaluate the injected total harmonic distortion (THD). A method to manage the responsibility for harmonic distortion that can determine the contributions to harmonic distortion at the point of common coupling between a customer and a utility is presented in [2]. Because of the bad effect of harmonic distortion on power quality and importance of harmonics on the life span and performance of the equipment connected to the power system, regulatory agencies such as IEC and IEEE have specified limits for selective harmonic distortion (SHD) in addition to the THD. An optimal solution for a selective harmonic elimination pulse width modulated (SHE-PWM) technique suitable for a high power inverter used in constant frequency utility applications, is presented in [3]. According to IEEE Standard 519-1992 [4] and IEC 61000 (1998) [5], maximum allowable THD and SHD are limited for both voltage and current. The THD and SHD limits for current specified by IEC 61000 3-4 (1998) for a balanced 3-phase, low voltage component for a selected range is given in Table 1.

To improve the power quality, several methods such as the use of higher-pulse converters; the modification of electric circuit configurations; the choice of transformer connections; and the application of harmonic filters have been proposed [6], [7]. Active power filters were developed for harmonic compensation and power factor correction [8]. In active filters, the compensation strategy is quite important and various strategies have been proposed to improve the performance of active filters [9]–[14]. Compensation strategies for control of shunt active filters are compared in [15].

A generalized and optimal control strategy (OFC) for harmonic compensation of utility lines is proposed in [16]. A simpler control scheme to generate the reference current for optimization of reactive volt-ampere or power factor subject to equality and inequality constraints imposed by harmonic conditions is proposed in [17].

In order to compensate harmonic distortion in current, different techniques have been reported using shunt active filters. Most of them assume a sinusoidal supply voltage and the goal is to achieve a sinusoidal source current. A few of these compensation techniques [16], [18], [19] have also considered the harmonics present in the supply voltage.

When the supply voltage is nonsinusoidal, any attempt to make harmonic free current results in reduction of power factor due to the harmonic present in the supply voltage. However, making the load voltage in phase and of the same shape as current may improve the power factor (PF), but the voltage distortion will be greater. Therefore, there is a trade-off between improvement in power factor and reduction in THD. Therefore, to solve this trade-off, it is necessary to optimize the PF and THD simultaneously. One solution is to optimize the PF while keeping THD within the limit. For a given active power, the PF can be improved by minimizing the total apparent input power S [20]. However, during this process some of the individual harmonics may exceed their limit. In [19], Lagrange function was used for the aforesaid optimization problem. Classical optimizations are limited to differentiable convex and continues algebraic objective functions and constraints and may depend on the specific function and/or constraints. On the other hand, due to the nature of these methods, they might converge to local solutions and fail to achieve the global one [21]. Furthermore, as the objective function complexity increases, these methods become more unreliable.

Recently, EAs such as genetic algorithms (GAs), particle swarm optimization (PSO), differential evolutionary (DE) and shuffled frog-leaping algorithm (SFLA), have made more contributions to solve optimization problem than other methods.

Although GA discovers the promising regions of search space quickly, it has two usual drawbacks: exploitation inability and premature convergence. PSO algorithm is a swarm intelligent technique inspired by food searching behavior of bird flocking [22]. This algorithm has been widely used in various fields of power system such as active power control, reactive power, and voltage control [23, 24]; power loss optimization [25] and voltage stability improvement [26]. PSO may be enormously affected by premature convergence and stagnation problem. DE algorithm is a simple population-based-evolutionary algorithm [27]. DE is also used to solve problems in power system [28, 29]. DE extracts the differential information (i.e., distance and direction information) from the current population of solutions to guide its further search. However, DE has no mechanism to extract and use global information about the search space [30].

In this paper, we proposed a new solution for control of selective and total harmonic distortion problem known as shuffled frog-leaping algorithm (SFLA). SFLA is a meta-heuristic optimization method based on observing and modeling the behavior of frogs. SFLA combines the benefits of the genetic-based memetic algorithms (MAs) and the social behavior-based PSO algorithm [31].

The rest of this paper is organized as follows: In Section 2, basic concepts for control of selective and total harmonic distortion are reviewed. Section 3 presents the mathematical formulation for control of selective and total harmonic distortion problem. In Section 4, SFLA optimization is described in detail. Simulation results and comparison with other algorithms are given in Section 5. Finally in Section 6, the conclusions are presented.