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A novel approach for fuzzy logic PV inverter controller optimization using lightning search algorithm

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ABSTRACT

Photovoltaic (PV) inverters convert DC voltage and current to AC quantities whose magnitude and frequency are controlled to obtain the desired output. While there are plenty of controllers, it is the fuzzy logic controller (FLC) that receives increasing attention. In this study, a novel metaheuristic optimization algorithm known as lightning search algorithm (LSA) is presented for solving the problem of trial and error procedure in obtaining membership functions (MFs) used in the conventional FLCs. The LSA mimics the natural phenomenon of lightning. It is generalized from the mechanism of step leader propagation. The proposed optimization algorithm considers the concept of fast particles known as projectiles. The probabilistic nature and tortuous characteristics of lightning discharges, which depend on the type of projectile, are modeled using various random distribution functions. To evaluate the reliability and efficiency of the proposed algorithm, the LSA is first tested using 10 benchmark functions with various characteristics necessary to evaluate a new algorithm. Then it is used in designing optimum FLC for standalone PV inverter. The result demonstrates that the LSA generally provides better outcome compared with the other tested methods with a high convergence rate.
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1. Introduction

Photovoltaic (PV) system has played very important role in the renewable energy (RE) technologies because PV systems are environment friendly, clean, and secure energy sources [1]. The PV based RE technologies has received a lot of attentions for stand-alone (SA) and grid-connected (GC) systems [2]. In the SA mode the inverter should be able to generate high quality power to the loads. An inverter is required to connect the load to the PV where the latter generates DC power [3]. The output waveforms, voltage and current, under the SA mode of operation of the inverter should be controlled based on the reference values. Therefore, a voltage source inverter (VSI) and a suitable voltage control approach are required [4]. The main feature of a good power inverter is its capability to provide constant amplitude sinusoidal voltage and frequency regardless the typing of the load it is connected to. The power inverter must also have the capability to quickly recover from transients affected by the disturbances without causing power quality problems. However, the large-scale use of PV generators raises many challenges, such as harmonic pollutions, low efficiency of energy conversion, fluctuation of output power, and reliability of power electronic converters [5].

Various inverter control techniques have been suggested by many researchers and discussed in [6]. FLCs have become increasingly popular in designing inverter controls because it include an advantage over the traditional controller by reducing the dependence on the mathematical model [7,8]. Nonetheless, the performance of FLCs depends on the rule basis, number of rules, and MFs. These variables are determined by a trial and error procedure, which is time consuming [9,10]. Thus, to overcome these limitations in FLC design, an optimization method was suggested in [11]. The method uses particle swarm optimization (PSO) algorithm and FLC for maximum power point tracking. However, PSO is prone to premature convergence and hence there is a need to find a better way to optimize the FLC. In a related work [12–14], the problem of adaptive fuzzy tracking control for a class of uncertain multiple-input–multiple-output pure-feedback nonlinear systems with immeasurable states was considered. In this work, fuzzy logic systems were first used to approximate the unknown nonlinear functions, and then a fuzzy state observer was designed to estimate the unmeasured states.

Many techniques have been suggested to deal with optimization problems. The optimum solution in most classical point-by-point methods is obtained by deterministic procedure [15]. As the

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size of the search space increase with the dimension of the optimization problem; the finding of the optimum solution for such problems using classical techniques becomes complicated [16]. Recently, computational intelligence optimization algorithms have been extensively used to solve complex optimization problems in various domains, including science, commerce, and engineering, because of their ease of use, broad applicability, and global perspective. computational-intelligence means search of solution for a problem by natural or artificial agents that address complex real-world problems [17]. These algorithms can be further divided into swarm intelligence methods and evolutionary algorithms (EAs). Swarm intelligence optimization algorithms generally use reduced mathematical models of the complex social behavior of insect or animal groups.

The most popular swarm intelligence methods are particle swarm optimization (PSO) [18], artificial bee colony (ABC) [19], and ant colony optimization (ACO) [20]. The PSO mimics the movements of bird flocking or fish schooling [21]. Inspired by the food-searching mechanism of honey bees, the ABC method uses the foraging behavior of these insects [22]. Meanwhile, ACO was developed based on the behavior of ants when seeking the optimal path between their colony and food source [20]. However, these swarm intelligence methods are limited by factors such as trapping in local minima and premature convergence [21–23]. To overcome these problems, variants of these algorithms have been developed with superior performance [21,23–25]. Other swarm intelligence methods, such as the gravitational search algorithm (GSA) [26], the harmony search algorithm [27], biogeography-based optimization [28], and the grenade explosion method [29], have also been developed.

EAs derive their working principles from natural genetic evolution. At each generation, the best individuals of the current population survive and produce offspring resembling them; hence, the population gradually comprises enhanced individuals. Operations such as recombination, crossover, mutation, selection, and adaptation are involved in this process [30]. The renowned paradigms of EAs are the genetic algorithm (GA) [30], evolutionary programming [31], differential evolution [32], evolutionary strategy [28], and genetic programming [33]. These algorithms are based on the principles of Darwinian theory and evolution theory of living beings. However, each algorithm follows specialized recombination, crossover, mutation, selection, and adaptation strategies. Similar to other metaheuristic algorithms, the aforementioned methods also have some drawbacks, such as slow convergence rate, difficulty in solving multimodal functions, and stagnation in local minima [34–36]. Advanced versions of EAs have been developed in recent years to improve the efficiency and performance of the aforementioned EAs; these advanced algorithms include stud genetic algorithm [36], fast evolutionary programming [35], adaptive differential evolution algorithm [37], and covariance matrix adaptation evolution strategy [38]. Not all algorithms and their variants provide superior solutions to some specific problems. Therefore, new heuristic optimization algorithms must be continuously searched to advance the field of computational intelligence optimization.

This study aims to introduce a novel metaheuristic optimization method called the lightning search algorithm (LSA) to solve the problem of trial and error procedure in obtaining membership functions (MFs) used in conventional FLCs. The LSA is based on the natural phenomenon of lightning. The proposed optimization algorithm is generalized from the mechanism of step leader propagation. It considers the involvement of fast particles known as projectiles in the formation of the binary tree structure of a step leader. Three projectile types are developed to represent the transition projectiles that create the first step leader population *N*, the space projectiles that attempt to become the leader, and the lead projectile that represent the best positioned projectile originated among *N* number of step leaders. The probabilistic nature and tortuous characteristics of lightning discharges, which depend on the type of projectile, are modeled using various random distribution functions. The utilization of the LSA is expected to improve the performance of FLCs for PV inverters. For this purpose, a unique objective function which considers the mean square error (MSE) of the three-phase PV inverter output voltage was formulated. The LSA aims to minimize MSE by adaptively tuning the MFs of FLC during the controller design phase.

2. Mechanism of lightning

Lightning is a fascinating and impressive natural phenomenon. The probabilistic nature and tortuous characteristics of lightning discharges originate from a thunderstorm. Among the common displays of lightning, downward negative cloud-to-ground lightning flashes (Fig. 1) are the most studied event in lightning research [39].

During a thunderstorm, charge separation occurs within the cloud, usually with a negative charge below and a positive charge above. This process creates a strong electric field. Free electrons generated by cosmic radiation or natural radioactivity are generally attached to oxygen molecules to form negative ions [40]. However, under high electric fields, a part of the electron velocity distribution possesses enough energy to ionize air, thereby generating additional electrons together with the original ones.

When one of these free electrons is accelerated by the electric field in the region where ionization probability is higher than attachment probability, an electron avalanche occurs. This phenomenon eventually causes a negative corona streamer. Nonetheless, the streamers are weak and become electrically isolated from their point of origin when the ionization probability is lower than the attachment probability.

The so-called streamer-to-leader transition happens at high electron densities and temperatures when narrow channels are thermalized. The negative or the step leader's movement from cloud to ground is not continuous but progresses through regular and discrete steps. For the leader to progress, a leader section in the vicinity in front of the old leader channel, called a space leader, develops from the preceding corona streamers. The space leader propagates backward until it connects to the old leader channel forming a long channel with a tip having the same electric potential [41]. A current wave is generated during this process.

Once this current wave reaches the tip of the new leader, a burst of corona streamers again propagates out in front of the new tip. Afterward, a new space leader originates in front of the current leader tip. The procedure is then repeated. The development is a

Fig. 1. Step leaders descending from a storm cloud.

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