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Economic analysis and power management of a stand-alone wind/photovoltaic hybrid energy system using biogeography based optimization algorithm

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ABSTRACT

The stand-alone energy system having a photovoltaic (PV) panels or wind turbines have low reliability and high cost as compared with wind/PV hybrid energy system. In this study, Biogeography Based Optimization (BBO) algorithm is developed for the prediction of the optimal sizing coefficient of wind/PV hybrid energy system in remote areas. BBO algorithm is used to evaluate optimal component sizing and operational strategy by minimizing the total cost of hybrid energy system, while guaranteeing the availability of energy. A diesel generator is added to ensure uninterrupted power supply due to the intermittent nature of wind and solar resources. Due to the complexity of the hybrid energy system design with nonlinear integral planning, BBO algorithm is used to solve the problem. The developed BBO Algorithm has been applied to design the wind/ PV hybrid energy systems to supply a located in the area of Jaipur, Rajasthan (India). Conventional methods require calculation at every single combination of sizing, operation strategy and the data for each variation of component needs to be entered manually and execute separately. Results show that the hybrid energy systems can deliver energy in a stand-alone installation with an acceptable cost. It is clear from the results that the proposed BBO method has excellent convergence property, require less computational time and can avoid the shortcoming of premature convergence of other optimization techniques to obtain the better solution.

1. Introduction

The public attention has remained focused on the renewable technologies as environmentally sustainable and convenient alternatives. Wind and solar power are the two most widely used renewable sources of energy among all renewable sources, since they feature definite merits as compared with the conventional fossil-fuel-fired generation. For instance, wind turbine generators (WTGs) neither generate pollution nor consume depleting fossil fuels. Photovoltaic (PV) systems produce no emissions, are durable, and demand minimal maintenance to operate [1]. Unfortunately, these renewable sources of energy are essentially intermittent and quite variable in their output. In addition, they require high capital costs. Power to off-grid location is usually supplied by a generator using diesel or petrol [2]. These generators are often available at night and only for a certain number of hours as explained by Musseli et al. [3]. During the designing of a hybrid system, it is necessary to select the size of various components with the operation strategy for the long-lasting, reliable and cost-effective system [4]. Many researchers have shown that hybrid energy systems are best suited to diminish dependence on fossil fuel by using available wind speed and solar radiations [5,6].

Hybrid energy system includes photovoltaic (PV) panels and/or wind turbines and batteries, etc. These energy systems are the cost-effective solutions to meet energy requirements of remote areas [7]. Das et al. [8] suggested that Evolutionary Algorithms (EAs), due to their population-based approaches, are able to detect multiple solutions within a population in a single simulation run and have a clear advantage over the classical optimization techniques, which need multiple restarts and multiple runs in the hope that a different solution may be discovered every run, with no guarantee [9]. However, numerous evolutionary optimization techniques have been developed since late 1970s for locating multiple optima (global or local). Due to significant improvement in the capability of computers in recent years [10], evolutionary algorithms (EAs), such as genetic algorithm (GA), evolutionary programming (EP), particle swarm

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optimization (PSO) [11] and differential evolution (DE) are being applied for solving various hybrid energy system optimization problems to overcome some of the drawbacks of conventional techniques [12].

Barley et al. [13] has suggested guidelines regarding main operation strategies, namely frugal discharge, load-following, the state of charge (SOC) set point and the full-power strategy. However, the SOC set point procedure is user-defined, and it is not optimized [14]. Frugal discharge is based on critical load, where if the net load is exceeding the critical load, then it is cost-effective to run the generator set. In load-following strategy, batteries are not charged by the diesel generator. Belfkira et al. [15,16] explained that diesel operating point is set to match the net load. SOC set point strategy is used to charge batteries at the user defined point from the diesel generator. Bernal-Agustin et al. [17] specifies that generator operates at full-power generation with the excess power is used to charge the batteries without dumping power. Otherwise, the generator is set to operate at the maximum point without dumping. In Full power strategy, the diesel generator is operated at full power for a minimum time at a low set point.

Seeling-Hochmuth [18] had investigated the application of the genetic algorithm to solve the optimization problem with various constraints. He further suggested an optimization concept combining system sizing and operation control. Koutroulis et al. [19] used Genetic Algorithm(GA) to minimize the total system cost based on the load energy requirements. Daming et al. [20], Gupta et al. [21] and Sopian et al. [22] explained a methodology of finding optimum component sizing and operational strategy using the genetic algorithm. Dufo-Lopez et al. [23] developed a program based on genetic algorithm, called HOGA, for optimizing the configuration of a PV–diesel hybrid system with AC loads and the control strategy. Hakimi et al. [24] applied PSO for multi-criterion design of the hybrid power generation system. Bansal et al. [25] use Meta Particle Swarm Optimization algorithm for finding the optimal size of the Wind/PV energy system. Ashok developed a reliable system operation model based on Hybrid Optimization Model for Electric Renewable (HOMER) [26] found an optimal hybrid system among different renewable-energy combinations while minimizing the total life-cycle cost. Dufo-Lopez et al. [27] later improved HOGA program to include fuel cell and hydrogen in the hybrid system. However, the control strategies in HOGA are same as used in HOMER. It is focused on maximizing the renewable energy components, while trying minimizing the use of the generator to provide for the load demand.

Very recently, a new optimization concept, based on biogeography has been proposed by Simon [28]. Biogeography Based Optimization (BBO) is a population-based evolutionary algorithm (EA)[29]. Biogeography is the study of the geographical natural distribution of biological organisms. In the BBO algorithm, each solution of the population is represented by a vector of integers. BBO algorithm adopts the migration operator to share information among solutions [30]. This feature is similar to other biology-based algorithms, such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). It makes BBO applicable to the majority of problems, where GA and PSO are applicable [31]. Simon [28] compared BBO with many other Evolutionary Algorithms on a wide set of benchmark functions. The results confirmed the excellent performance of BBO. The Markov analysis also proved that BBO outperforms GA on basic unimodal, multimodal and deceptive benchmark functions when used with low mutation rates. The versatile properties of BBO algorithm encouraged the authors to apply this algorithm to solve the non-convex, complex optimal sizing problem of hybrid energy systems.

Hybrid energy system sizing is a nonlinear integral problem, which is a complex problem. The objective of this paper is to explore the application of the BBO algorithm to the hybrid energy system design problem. The combination of components represents the sequence of the suitability index variables (SIVs), which determine the total cost of the system. After the migration operation in BBO, a SIV in the immigrated island (a bad solution) accepts the sharing information from the emigrated island (a better solution). To keep the new solution feasible, adjust the SIV which has the identical component cost [32].

The BBO algorithm has certain unique features, which overcome several demerits of the conventional methods as mentioned below

(1) In BBO and PSO, the solutions survive forever although their characteristics change as the optimization process progresses. However, solutions of evolutionary-based algorithms like GA, DE etc. "die" at the end of each generation. Due to the presence of crossover operation in evolutionary based algorithms, many solutions, whose fitness is initially favorable, sometimes lose their quality in later stage of the process. In BBO, there is no crossover like operation as the solution gets fine-tuned gradually as the process goes on through migration operation. Elitism operation has made the algorithm more efficient in this aspect and gives an edge to BBO over other techniques.
(2) In PSO, solutions are more likely to clump together in similar groups. While in the case of BBO, solutions do not have the tendency to cluster due to its new mutation operation.
(3) BBO involves fewer computational steps per iteration as compared to other algorithms like GA, PSO, DE etc. Due to this, BBO results are faster in convergence.
(4) In BBO, poor solutions accept a lot of new features from good ones, which may improve the quality of solutions. This is a unique feature of BBO algorithm compared to other techniques. At the same time, this makes constraint satisfaction to be much easier, compared to other algorithms.

In this paper, the BBO optimization algorithm uses the static models of the wind turbine, the PV panel, the battery, the inverter and on the dynamic evaluation of the wind and solar-energy potential. BBO is used to simply solve the size of the hybrid PV/wind energy system by considering economical and reliability constraints of the system. The new method is suitable to deal with the complex design of hybrid energy system and can avoid the local minimum trap. The developed BBO methodology has been applied to design the stand-alone hybrid wind/PV systems to power supply a varying load located in the area of Jaipur, Rajasthan (India) with geographical coordinates defined as: latitude: 26°92 N, longitude: 75°82 E and altitude: 431 m above sea level.

This paler is organized as follows. In Section 2, the hybrid energy system and its components are explained. Section 3 describes the optimization problem of hybrid system and Section 4 explains the simplified BBO. In Section 5, detail of Case study data is presented and Section 6 shows the comparison of Hybrid Optimization Model for Electric Renewable software (HOMER) [26], Biogeography Based Optimization (BBO) [28], Genetic Algorithm (GA) [22], particle swarm optimization (PSO) [23], comprehensive learning particle swarm optimization (CLPSO) [33] and ensemble of mutation and crossover strategies and parameters in DE (EPSDE) algorithm [34] algorithms. In Section 7, the results of proposed BBO algorithm have been explained and discussed.

2. Hybrid energy systems

A hybrid renewable generation system comprises of wind turbine generators (WTGs) of different types, PV panels (PV), storage batteries (SB) with diesel generator are shown in Fig. 1. In the hybrid generation system, they are integrated and complement with each other in order to meet performance targets of the generation systems and access to the most economic power generation.