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BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting

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ABSTRACT

Rising carbon emission or carbon footprint imposes grave concern over the earth's climatic condition, as it results in increasing average global temperature. Renewable energy sources seem to be the favorable solution in this regard. It can reduce the overall energy consumption rate globally. However, the renewable sources are intermittent in nature with very high initial installation price. Off-grid Small Autonomous Hybrid Power Systems (SAHPS) are good alternative for generating electricity locally in remote areas, where the transmission and distribution of electrical energy generated from conventional sources are otherwise complex, difficult and costly. In optimizing SAHPS, weather data over past several years are generally the main input, which include wind speed and solar radiation. The weather resources used in this optimization process have unsystematic variations based on the atmospheric and seasonal phenomenon and it also varies from year to year. While using past data in the analysis of SAHPS performance, it was assumed that the same pattern will be followed in the next year, which in reality is very unlikely to happen. In this paper, we use BBO optimization algorithm for SAHPS optimal component sizing by minimizing the cost of energy. We have also analysed the effect of using forecast weather data instead of past data on the SAHPS performance. ANNs, which are trained with back-propagation training algorithm, are used for wind speed and solar radiation forecasting. A case study was used for demonstrating the performance of BBO optimization algorithm along with forecasting effects. The simulation results clearly showed the advantages of utilizing wind speed and solar radiation forecasting in a SAHPS optimization problem.

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Contents

1. Introduction . . . 1367
2. Small autonomous hybrid power system (SAHPS) . . . 1368
   2.1. Wind turbine generators (WTG) . . . 1368
   2.2. Photovoltaic generation (PV) . . . 1368
   2.3. Storage batteries (SB) . . . 1368
3. Optimization problem of SAHPS . . . 1368
   3.1. Cost of SAHPS power sources . . . 1368
   3.2. Cost of other parameters in SAHPS . . . 1368
   3.3. Constraints in the optimization . . . 1369
4. Forecasting in hybrid energy system . . . 1369
   4.1. Artificial neural network model . . . 1369
   4.2. Wind speed forecasting model . . . 1369
   4.3. Solar radiation forecasting model . . . 1370
   4.4. Testing the performance of the models . . . 1370
5. Biogeography-based optimization (BBO) . . . 1370
6. The BBO algorithm . . . 1371
7. Evaluation of the effect of forecasted data on optimization . . . 1371
8. Conclusion . . . 1373
References . . . 1374

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1. Introduction

Electrical energy, one of the essential requirements of the modern world, has significant contribution towards the overall development of a nation. The electrical power generation system based on natural resources such as oil, coal and natural gases is unsustainable as these natural resources depend on the finite fossil fuel reserves, which are depleting gradually. If the present trend of exploitation of natural resources continues, the worldwide carbon emission level will rise to eight to twelve Giga tonnes by 2030, 62 percent higher as compared to the year 2002. With the increasing demand for electricity along with significant depletion in natural resources and several environmental issues, there is a need for advancement in renewable energy sources. In this regard, research and development (R&D) in the area of renewable energy technology can offer solutions in above all areas.

Several optimization algorithms have been developed [1] for SAHPS optimization using past years meteorological data of solar radiation, wind speed, etc. Protogeropoulos et al. [2] used data for average and worst months and proposed two optimization methods for stand-alone hybrid energy systems. Morgan [3] also proposed method based on the data for worst month – the month, which requires the maximum size of photovoltaic module and wind turbine is selected as the worst month. Borowy and Salameh [4] developed a solar-wind hybrid system optimization algorithm using hourly meteorological data and load demand. Zhou et al. [5] and Notton et al.[6] proposed another optimization algorithms based on time series meteorological data, while the predictive algorithm proposed by Celik [7] uses monthly average wind speed and solar radiations. Other new optimization models have also been developed incorporating some components and weather constraints [8,9].

Optimization techniques proposed by the researchers are based on different methods such as graphical, iterative technique, artificial intelligence and multi-objective methods. Borowy and Salameh [4] developed a solar-wind hybrid system based on graphical construction technique using hourly meteorological data and load demand for past 30 years. Bagul [10] proposed a sizing method using a three-event probability approximation, while Yang et al. [11] proposed an HSWSO iterative technique using LPSP model. Similarly, Kellogg et al. [12] proposed an iterative procedure for making demand gap near to zero.

Puri [13] has given a linear programing based convex optimization solution for hybrid energy system using power reliability criterion based on FLNS (Fraction of Load that can Not be Served) calculation. Yadav et al. [14] has designed a wind-diesel hybrid energy system through Hybrid Optimization Model for Electric Renewable (HOMER) and has shown the advantage of wind-diesel system as compared to diesel system. Sureshkumar et al. [15] also has used HOMER software for hybrid renewable energy system optimization and economic analysis. Banos et al. [16] have given a review of current state of the art about hybrid energy system optimization using computational methods and latest advances and future directions for Research and Development in this field. Haidar et al. [17] simulated a PV-diesel hybrid energy system through Hybrid Optimization Model for Electric Renewable (HOMER).

Belfkira et al. [18] presented a deterministic algorithm for optimization of hybrid wind/PV/diesel energy system. Luna-Rubio et al. [19], Erdinc et al. [20] and Saber et al. [21] provided a detailed analysis about hybrid energy system optimization methodologies and presented comparison between advantages and disadvantages of various sizing methodologies developed in the recent years. Mohammed et al. [22] discuss critical state-of-the-art review of hybrid energy systems planning and indexes multi-objective methods for optimal design. Tan et al. [23] summarizes different modelling approaches for RAPS system architecture design, component modelling and size optimization. They also discuss the technical challenges associated with RAPS systems design and control.

Methods based on artificial intelligence such as artificial neural networks (ANNs), genetic algorithms (GAs) and particle swarm optimization (PSO) algorithm are widely used for finding the optimal sizing solution by minimizing the system cost. Optimization algorithms based on GAs for optimum design have been reported in literature [24–26]. Dufo-Lpez [27] and Seeling [28] implemented GAs for optimization, and simulation time has been reduced. Gupta et al. [29] has proposed GA for finding the optimal sizing coefficient of wind/PV hybrid energy system in remote areas. For optimal sizing calculation, Kalogirou [30] has developed ANNs and GAs. Optimization methods based on fuzzy logic and GA for sizing, battery and diesel generator scheduling have also been presented [31,32]. Using evolutionary algorithm for optimization based on multi-objective optimization which includes resources, load, CO_2 emission and costs have been analysed [33]. Strength pareto evolutionary algorithm (SPEA) for hybrid system optimization with multi-objective of emission as well as cost minimization has also been reported [34]. Dufo-Lpez and coworkers [35] were the first to present a triple multi-objective optimization algorithm for cost, CO_2 emission and load. Later, Bansal et al. [36] and Kumar et al. [37] have proposed a biogeography based optimization (BBO) algorithm for finding the optimal size of standalone hybrid energy systems.

Datta et al. [38] has shown that the solar radiation forecasting using soft computing technique (Multi-Layer Perceptron Neural Network) gives better and accurate results as compared to statistical method (Multiple-Linear Regression). Lei et al. [39] have presented a bibliographical survey on the state-of-the-art research and developments in wind speed and power forecasting. Catalao et al. [40] proposed a novel hybrid approach using wavelet transform, PSO algorithm and an adaptive-network-based fuzzy inference system for short-term wind forecasting and compared the performance with seven other approaches. Rahmati et al. [41] compared the performance of BBO algorithm with similar algorithm that is GA and algorithms and shown that the BBO performance is better than other algorithms. Khan et al. [42] analysed the performance of five neural network training algorithms namely two gradient descent algorithms – back propagation and Levenberg-Marquardt – and three population-based heuristic – Bat Algorithm, Genetic Algorithm, and Particle Swarm Optimization – and has shown that the population-based heuristic algorithms are better as compared to gradient descent algorithms. Hong et al. [43] applied the fuzzy-c-means (FCM) to cluster the operation states and the genetic algorithm with Markov model to determine the optimal size of hybrid energy system. George et al. [15] proposed Markov chain Monte Carlo (MCMC) method for wind power forecast and has shown that MCMC method is excellent fit for probability density as well as autocorrelation function of the generated wind power time series. Mellit et al. [44] applied artificial neural network for generating sequences of global solar radiation and then compared the result with traditional models AR, ARMA, Markov chain, MTM and measured data.

The wind speed forecasting results was compared with autoregressive integrated moving average reference model (NRM) proposed by Nielsen et al. [45], neuro-fuzzy (NF) suggested by Pousinho et al. [46], Markov chain Monte Carlo (MCMC) proposed by George et al. [47] and wavelet-PSO-ANFIS approach (WPA) developed by Catalao et al. [48]. The solar radiation forecasting results was compared with Radial Basis Function Neural Network (RBFNN) proposed by Mohandes et al. [49], Recurrent Neural Network (RNN) proposed by A. Chaouachi et al. [50], Empirical method suggested by *K*. Spokas et al. [51] and Markov chain given by Mellit et al. [44].

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