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A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources

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ABSTRACT

In this paper, a hybrid configuration of ant colony optimization (ACO) with artificial bee colony (ABC) algorithm called hybrid ACO–ABC algorithm is presented for optimal location and sizing of distributed energy resources (DERs) (i.e., gas turbine, fuel cell, and wind energy) on distribution systems. The proposed algorithm is a combined strategy based on the discrete (location optimization) and continuous (size optimization) structures to achieve advantages of the global and local search ability of ABC and ACO algorithms, respectively. Also, in the proposed algorithm, a multi-objective ABC is used to produce a set of non-dominated solutions which store in the external archive. The objectives consist of minimizing power losses, total emissions produced by substation and resources, total electrical energy cost, and improving the voltage stability. In order to investigate the impact of the uncertainty in the output of the wind energy and load demands, a probabilistic load flow is necessary. In this study, an efficient point estimate method (PEM) is employed to solve the optimization problem in a stochastic environment. The proposed algorithm is tested on the IEEE 33- and 69-bus distribution systems. The results demonstrate the potential and effectiveness of the proposed algorithm in comparison with those of other evolutionary optimization methods.

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1. Introduction

In recent years, distribution energy resources (DERs) became attractive due to its technical, economic and environmental benefits. DER is a small electrical power source located near the customer's site in a distribution network. There are different DER types such as fuel cell (FC), gas turbine (GT), micro-turbine and renewable distributed generation (RDG). The environmental advantage of DER covers a wide range of benefits such as the reduction of greenhouses gases, new transmission line development, and sound pollution. In addition, RDGs are to play a key role in dealing with environmental concern due to their ability to produce green power and reduce the dependency on fossil fuels. Nowadays, renewable energy sources supply 14% of the total world energy demand and include solar, wind, biomass, etc. [1,2].

Parallel to the environmental benefits, renewable and non-renewable distributed generation resources can provide significant technical and economic advantages for operations as well as utilities. Adding DER to the competitive electricity production impacts on different technical benefits like reducing losses, improving voltage profile and power quality [3]. Since the installation of different energy sources in a power system may have significant impacts on electric power generation, it requires careful consideration for the installation of any new energy sources to be very well planned. However, different benefits of DER depend on location, technology and capacity [4].

There are different techniques for solving the optimal location and size of energy sources connected to the distribution network. Research for the optimal allocation of DER has been investigated using the conventional algorithms [5] including the analytical [6] and numerical [7] methods, and evolutionary methods such as bacterial foraging optimization [8], particle swarm optimization with constriction factor approach (PSO–CFA) [9] and imperialist competition algorithm (ICA) [10]. Therefore, different evolutionary algorithms (EA) have been applied to the optimization problem of multiple DERs. Nevertheless, integration of hybrid energy systems into the current power systems offers various technical assessments and it has become an essential issue. The authors of

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Ref. [11] have employed a hybrid modified shuffled frog algorithm and deferential evolution to determine the optimal location with respect to power losses, energy cost and emissions. Another study has developed a hybrid genetic algorithm (GA) and particle swarm optimization method for multi-objective location and sizing of DERs [12]. The authors have concluded that the combined method has a higher probability of finding the optimum solution; however, it does not consider different strategies by installing multiple DERs. The authors of [13,14] have presented the artificial bee colony algorithm (ABC) to optimally solve the allocation problem of DER. However, different DER technologies have various impacts on power system operation, control, and stability. In Ref. [15], optimal placement of renewable energy sources including three different types of RDG: photovoltaic, wind and fuel cell are investigated by using the multi-objective modified honey bee mating optimization algorithm. In [16], fuel cell power plants (FCPPs) have been used as energy sources for planning with respect to operation and economic problems while hybrid energy systems are best suited to reduce the dependence on fossil fuel. Genetic algorithm has been used to connect multiple wind turbines (WTs) in distribution networks [17,18]. These approaches are available to find the location or size of only a wind turbine. On the other hand, the integration of energy sources has different impacts on power system operation. However, most studies do not consider the wind uncertainty.

Wind turbines as renewable technologies are expected to play important role for power systems in electricity generation and operations. According to the statistics, the installed wind power is 238,351 MW in 2011; the increase of the installed capacity is nearly 75% over the period of 2005–2011 [19]. In its role as electricity generation several countries have achieved rapid expansion such as China, France, Canada, USA and UK with the growth rate of around 98%, 88%, 87%, 80% and 79% around the period 2005–2011, respectively. The world wind energy association (WWEA) has predicted that the total electrical power generated by wind will reach 1,500,000 MW in 2020 [19].

The use of wind turbines can provide significant technical, environmental and economic benefits. However, wind is one of the major sources suffering from uncertainty. Due to increasing penetrates of wind power into the systems operation and the inherent uncertainty in wind, there is an urgent need for a stochastic study for power system planning, especially in dealing with modern power systems [20,21]. Many methods have been proposed to deal with the uncertainty problem [22]. One of the most popular methods is the Monte Carlo simulation to accommodate probabilistic analysis through deterministic analysis [23]. With regards to Monte Carlo simulation, it should be noted that a great deal of simulation and computing is required to achieve convergence [24]. An alternative way is through analytical methods; these use mathematical assumptions to simplify the problems such as independency or liner dependency of different random variables [25]. Lastly, the approximate method provides a balance between speed and accurate by an approximate description. Among the well-known approximate methods, the point estimated methods (PEMs) stand out [26].

To the best of our knowledge, no research work in the area considered the combined ant colony optimization (ACO) and artificial bee colony algorithms called hybrid ACO–ABC algorithm to solve the optimal placement and sizing of distributed energy resources (DERs). The main contribution of this paper is to develop the hybrid ACO–ABC algorithm to optimally locate DERs considering the wind and load uncertainties as a stochastic programming framework. The Weibull probability density and normal distribution functions are used to model the wind and load uncertainties, respectively. Also, the probabilistic power flow based on the PEM is utilized to study the stochastic nature of wind generation and load demands during optimization processes. In addition, the hybrid ACO–ABC algorithm takes advantages of the global search ability of ABC and the local search ability of ACO algorithm. The ACO algorithm is a probabilistic technique for solving computational problems and gives the optimal solution through graphs although it may be trapped in a local optimal solution different from a global optimal one [27]. For this reason, the ABC algorithm is used to escape from the trap of local optimal solution and to quickly find the global optimal solution [28]. Therefore, in this paper, the location of DER and its size are optimized by ACO and ABC algorithms to correlate discrete and continuous variables, respectively. The best location and size of DERs (i.e., gas turbine, fuel cell and wind turbine) are selected to optimize power losses, voltage stability index (VSI), total emission and electrical energy cost as objective functions in single- and multi-objective optimization frameworks. The proposed algorithm uses the Pareto optimal solution and saves the non-dominated optima into an external archive to solve the multi-objective problem. The effective fuzzy decision making tool is incorporated in the proposed algorithm to softly switch between the Pareto optimal solutions. So, the fuzzy decision making tool offers a better judgment among the Pareto optimal solutions based on the selected weight values and thereafter select the best compromise one by the proposed algorithm. Furthermore, the proposed algorithm is implemented on the IEEE 33- and 69-bus distribution systems in two different scenarios. The results obtained by the proposed algorithm show that the proposed algorithm is outperformed by the other evolutionary optimization methods such as PSO–CFA [9], ABC [14] and Modified Teaching–Learning Based Optimization (MTLBO) [29] from technical, environmental and economic point of view.

The remainder of this paper is organized as follows: Section 2 explains the optimal placement and sizing problem formulation. In Section 3, the necessary background and fundamentals of the ABC and ACO algorithms and the implementation of the proposed hybrid ACO–ABC algorithm are described into three subsections. Section 4 presents the subject of the point estimated method, modeling wind and load uncertainty in power systems. Section 5 contains simulation results followed by conclusions.

2. Problem formulation

The main goal of optimization DER is to determine the best location and size of new energy sources with minimized specific objective function. In this section the objective functions and constraints are explained.

2.1. Objective functions

In this paper, the following objective functions are considered:

2.1.1. Minimization of power losses

Minimizing the total electrical energy losses of distribution network is an important goal of implementing sources, which can be formulated as follows [21]:

$$f_1(X) = \sum_{i=1}^{n_{br}} R_i |I_i|^2 \tag{1}$$

where n_{br} is the number of branches, R_i and I_i are the resistance and the current magnitude of i th the branch, respectively.

2.1.2. Voltage stability index

Under power systems planning and operation the voltage stability is one of the most significant security indices. DER has a profound impacted on the voltage stability index and it will be changed by connecting DER. In [30], Chakravorty and Das proposed

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