Computers and Electrical Engineering 000 (2018) 1–14

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Dual stage approach for optimal sizing and siting of fuel cell in distributed generation systems[☆]

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ARTICLE INFO

Article history:
Received 12 September 2017
Revised 1 February 2018
Accepted 1 February 2018
Available online xxx

Keywords:
ABC
Fuel cell
Distributed generation
Voltage stability
Voltage profile

ABSTRACT

This paper addresses the challenges in localizing and determining the sizing of fuel cells to connect to distributed generation systems. To handle the problem, dual stage intelligent methodology is adopted in the paper. In the first stage, the neural network is exploited to determine the optimal location, whereas the second stage determines the optimal sizing for fuel cells is done by Artificial Bee Colony (ABC) algorithm. An improved version of ABC is proposed to determine the optimal sizing (in combination with the network). The proposed methodology is experimented with four IEEE benchmark test bus systems and compared with five conventional algorithms. The results demonstrate the superior performance of the proposed methodology. Finally, the simulation results revealed that the proposed method is superior to the other conventional methods.

1. Introduction

The development of Distribution Generation (DG) system from the existing traditional power systems is of great concern due to the economic and the environmental factors [7]. The DG system is from few kW to 50 MW [18] and it is used because of the advancement of the small green technologies [8]. The DG types based on the terminal characteristics include DGs capable of injecting—the real power, the reactive power, real and reactive power, real but consuming reactive power. The DG deployment must be done properly for better installation of the system. By proper installation, the DGs have many advantages such as power loss reduction, high reliability, peak shaving, improvement in power quality, low cost for maintenance, fewer construction schedules [9–11].

There is a problem for allocating the DG units and so various optimization methods are developed which can be divided into the optimal size and optimal location problem optimizations. The deterministic, heuristic and analytical methods are used for better optimization. The methods include software procedure on genetic algorithm [12], Tabu search method [13,14], Ant Colony Optimization (ACO) method [15], Particle Swarm Optimization (PSO) method [16], non-dominated sorting Genetic Algorithm (GA) II method [17]. Recently, the combinations of algorithms are presented in various works [18].

The challenges faced in the DG units allocation includes the decreased security, fluctuations in the circuit level, voltage instability, complexity, optimal location and sizing, penetration level. So these challenges have to be given importance

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. N.K. Yadhav.

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https://doi.org/10.1016/j.compeleceng.2018.02.003
0045-7906/© 2018 Published by Elsevier Ltd.

and many research works are in the process of finding an optimal solution. Few recent works in the area of distribution generation systems are reviewed in the next Section.

This paper addresses the problems and comes out with a dual stage methodology. The first stage intends to determine the optimal location and the second stage determines the optimal sizing for fuel cells to be connected to the bus system. The first stage incorporates neural network, through which the optimal location of fuel cells can be estimated. Based on the results, the optimal sizing for fuel cells is determined using an improved version of ABC. The rest of the paper is organized as follows. Section 2 reviews the literature and Section 3 derives the unified objective model. Section 4 details the methodology adopted to determine the optimal location and the sizing of the fuel cells. Section 5 discusses the results and Section 6 concludes the paper.

2. Literature review

This section provides the description of recent state-of-the-art contribution and the associated problem statement regarding the optimal sizing and allocation of fuel cells in DG system.

2.1. Related works

In 2013, Mojarrad et al. [1] proposed a novel algorithm, which was a fuzzy satisfying method, developed to tackle the issue of distributed generation units sizing and multi-objective optimal placement in the distribution network. The developed model was related to the Hybrid Modified Shuffled Frog Leaping Algorithm (MSFLA) and the main aim was to reduce the loss of electrical energy, emission of pollutants and the energy investments.

In 2014, Moradi et al. [5] developed the multi-objective Pareto Frontier Differential Evolution (PFDE) algorithm for providing an answer to the distribution expansion planning problem which was based on the DG sources. For solving the issue, they mainly included three factors such as power loss, voltage stability and network voltage fluctuations and the results proved the proposed methods efficacy in identifying the exact solutions.

In 2016, Poornazaryan et al. [2] have worked on solving the problems of power loss and voltage stability. Considering this problem, they developed a novel method, which was a modified form of Imperialistic Competitive algorithm (ICA) that solves the optimization problem with discrete variables.

Kansal et al. [3] developed a hybridized technique based on the analytical method and the heuristic search method for solving the problem of optimal location of the multiple DGs with the aim of reducing the power loss.

In 2015, Mohandas et al [4] used a Chaotic ABC (CABC) algorithm for the issue of voltage stability and the power loss. So, for minimizing the power loss, it was necessary to optimize the location and the sizing of the distribution generation systems.

Murty and Kumar [6] have worked on the distribution systems and compared the power stability index, power loss sensitivity and the developed voltage stability index for identifying the optimal location and sizing of the distributed generation in the radial distribution network.

2.2. Challenges

Since localizing the optimal point and the optimal size for placing the fuel cell in a DG system is non-convex optimization problem, numerous bio-inspired optimization algorithms [1,3–5] and nonlinear programming based algorithm [2] have been reported in the literature. The qualitative analysis on any optimization algorithm must ensure the convergence rate, global searching ability, local searching ability, evading from local optima, less computing cost, reduced number of parameters to be tuned, adaptiveness over the real-life environment and many more. However, it is impractical for any algorithm to dominate in all of the aforementioned parameters. It depends upon the application where the algorithms are being used and the performance constraint to be focused more. In such perspective, an algorithm is said to be advantageous and poor in performance.

According to the review, the frog leaping algorithm [1] has more benefits of about high efficient computing performance, global searching ability, etc. However, the primary requirements of adaptiveness over real-time performance and solving nonlinear problems have not been met by it. Moreover, it suffers from premature convergence and so it cannot evade from the local optimal point. The differential evolution [5] is a classical evolutionary algorithm used in most of the optimization problems. Its instability in the final iterations limits its use for determining the optimal placement of fuel cells. Similarly, the PSO [3] is a classical swarm intelligence, which has been known for its less computational complexity and no stagnancy with the solutions. However, these algorithms stick with local optimal under multimodal problem environment. The usage of chaos theory and ABC algorithm together [4] can overcome the drawback of sticking with local optima. However, they skip the second order information about the problem model and as a result, the convergence rate is poor. The customized algorithm such as imperialistic competitive algorithm [2] can overwhelm the majority of the aforesaid problems, but multiple initialization and usage of penalty constraints limit the optimization performance and the reliability of the solutions.

Above all, the given problem model is a bi-level optimization problem in which the defined fuel cell should have the optimal capacity and it should be placed in an optimal location to meet the stability and the demand of the power system. Hence, a more robust optimization algorithm is essential to handle such diversified problem constraints.

Please cite this article as: T.C. Subramanyam et al., Dual stage approach for optimal sizing and siting of fuel cell in distributed generation systems, Computers and Electrical Engineering (2018), https://doi.org/10.1016/j.compeleceng.2018.02.003