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Distributed generations planning using flower pollination algorithm for enhancing distribution system voltage stability

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Abstract Distributed generations (DGs) have been utilized in some electric power networks. Power loss reductions, voltage improvement, increasing reliability, postponement of system upgrading and environmental friendliness are some advantages of DG-unit applications. This paper presents a new optimization approach that employs a flower pollination algorithm (FPA) to determine the optimal DG-unit's size and location in order to minimize the total system real power loss and improve the system buses voltage. The FPA is a new metaheuristic optimization technique and it is inspired by the reproduction strategy of the flow pollination process of flowering plants. To reveal the validity of the FPA algorithm, IEEE 33-bus, 69-bus and 136-bus radial distribution test systems are examined with different test cases of the objective function using the MATLAB. Furthermore, the results obtained by the proposed FPA algorithm are compared with other metaheuristic optimization techniques such as backtracking search optimization algorithm, artificial bee colony, and selection algorithm. The outcomes verify that the FPA algorithm is efficient, robust, and capable of handling mixed integer nonlinear optimization problems.

1. Introduction

The interest in distributed generation (DG) in power system networks has been growing rapidly. This increase can be explained by factors such as environmental concerns, the restructuring of electricity businesses, and the development of technologies for small-scale power generation. DG can be alternative to the industrial, commercial and residential application. Several definitions are available for DG all over the world, depending upon plant rating, generation voltage level,

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point of connection, etc. It can be concluded that the DG is an electrical power generation within distribution system or on the customer side of the system [1].

DGs are anticipated to play a great role in developing of electrical power systems. Studies have predicted that they are about 20% of the new generations being installed [2]. The increment in active power loss represents loss in savings to the utility as well as a reduction in feeder utilization. Studies have shown that 70% of power losses are due to distribution system and the losses resulting from Joule effect only account for 13% of the generated energy [3]. This non-negligible amount of losses has a direct impact on the financial results and the overall efficiency of the system.

DG affects the power flow and the voltage on the buses of the system. The non-optimal placement of DG can increase the system losses and thus make the voltage profile lower than the allowable limit. It must also be reliable of proper size so that it can give the positive impacts or be known as 'system support benefits'. These benefits include improved voltage profile, reduce the losses, increase the distribution capacity, and improve the reliability of utility system [4,5].

In practice, in the distribution network, load pattern is varying with time. The optimal location and size of DG determined under invariant loads may not be optimal under time-varying loads and the optimal DG size may vary with varying load demand. But in practice, it is not economically feasible to change the DG size with changing load demand. Therefore, for planning purpose, an optimal size and location of DGs can be determined by considering peak, average, or combination of the two loading conditions to get the maximum benefit of DGs [6].

Previously, different methodologies have been developed to determine the optimum size and location of DG [7]. A simple search algorithm for optimal sizing and placement of DG based on the minimization of losses in a radial distribution system is proposed in [8]. This method consumes more computational time to solve and is not valid for multi-objective optimization problem. Optimization based algorithm has also been proposed by [9] to find the optimal location for DG with maximum profit using dynamic based programming. In [10], Clonal selection algorithm (CSA) is proposed to determine the optimal DG-unit's size and location is determined by loss sensitivity index. Other studies have been conducted on DG installations which consider sizing and allocation using Embedded Meta Evolutionary-Firefly Algorithm (EMEFA) [11]. This method focused on the effect of population size on loss and cost minimization while improving the performance of the system. In [12], an optimization algorithm based on the genetic algorithm was introduced to address the optimal distributed generation sizing and siting for voltage profile improvement, power losses, and total harmonic distortion (THD) reduction in a distribution network with high penetration of nonlinear loads. The proposed planning methodology takes into consideration the load profile, the frequency spectrum of nonlinear loads, and the technical constraints such as voltage limits at different buses (slack and load buses) of the system, feeder capacity, THD limits, and maximum penetration limit of DG units. In [13] a probabilistic planning approach is proposed for optimally allocating different types of distributed generator (i.e. wind-based DG, solar DG and non-renewable DG) into a harmonic polluted distribution system so as to minimize the annual energy losses and reduce the harmonic distortions. The performance of DG in distribution networks was also being studied in [5] using the technique of Hybrid Mutation-Evolutionary Programming (HM-EP) and Particle swarm Optimization (PSO). Calculation of location and size of the DG are determined separately, which means different method is applied for sizing and location. Thus, it may result in the solution trap in local optimum so Ref. [14] provides a solution to the output power and location of multiple DG sources by using modified Artificial Bee Colony algorithm to avoid this issue. Big bang big crunch method was used in [15] to find optimal site and size of DG to minimize power loss for balanced and unbalanced distribution systems. The backtracking search optimization algorithm (BSOA) was used in DS planning in [16] with multi type DGs while in [17], BSOA was used to study the impact of various load models on DG placement and sizing and also the time of calculation to find optimal size and location was obtained.

The flower pollination algorithm (FPA) is a new meta-heuristic optimization technique and it is inspired by the reproduction strategy of the flow pollination process of flowering plants [18–20]. The FPA is used to solve real optimization problems [21,22]. In [21] the FPA is used to select the optimal location of distribution transformers in a low-voltage grid, while in [22], the optimal control in multi-machine system with generalized unified power flow controller was discussed.

In this paper, the FPA is used to determine the optimal size and location of single and multi-DGs to minimizing the power losses of the distribution system as much as possible and enhancing voltage profile of the system using voltage index. IEEE 33-bus, 69-bus and 136-bus systems are examined as test cases with different scenarios of the objective function. The results in this paper are compared with performance of BSOA, artificial bee colony (ABC), and clonal selection algorithm (CSA).

2. Problem formulation

2.1. Load flow

On account of the some inherent features of distribution systems such as radial structure, large number of nodes and a high R/X ratio, the conventional techniques such as Newton–Raphson and fast decoupled method may fail or have problems when dealing with distribution networks. In this paper, the load flow is based on the forward/backward sweep technique because it is a powerful method and has been widely used in distribution [23].

2.2. Objective functions

The objective function proposed in this study is defined as follows:

$$\mathrm{OF} = min[(W_L * f_1) + (W_v * f_2)] \tag{1}$$

where OF is the objective function, f_1 is the total real power losses, f_2 is the voltage index (VI), W_L is the weighting factor for power loss and W_v is the weighting factor for VI.

W_L and W_v are the weighting coefficients representing the relative importance of the objectives. It is usually assumed that [24]: