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ORIGINAL ARTICLE

Optimal siting of capacitors in radial distribution network using Whale Optimization Algorithm

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Abstract In present days, continuous effort is being made in bringing down the line losses of the electrical distribution networks. Therefore proper allocation of capacitors is of utmost importance because, it will help in reducing the line losses and maintaining the bus voltage. This in turn results in improving the stability and reliability of the system. In this paper Whale Optimization Algorithm (WOA) is used to find optimal sizing and placement of capacitors for a typical radial distribution system. Multi objectives such as operating cost reduction and power loss minimization with inequality constraints on voltage limits are considered and the proposed algorithm is validated by applying it on standard radial systems: IEEE-34 bus and IEEE-85 bus radial distribution test systems. The results obtained are compared with those of existing algorithms. The results show that the proposed algorithm is more effective in bringing down the operating costs and in maintaining better voltage profile.

1. Introduction

Electric power distribution system normally operates at low voltage levels and current is generally high. Majority of the distribution systems feed inductive loads which leads to higher power losses in the distribution network and poor power factor accompanied by voltage sags. So, the cost of the power increases. It is reported that about 13% of the total generation is lost in the low voltage distribution network as line losses [1]. Therefore it is necessary to find alternate approaches to overcome these problems and ensure stability, reliability and quality of electric power supply. Connecting capacitors is a well-known solution to the above stated problems [2,3]. Shunt capacitors effectively reduce power loss in the system. Generally, these are used as reactive power compensators in the network. Capacitors will improve the overall system performance by maintaining voltage levels within the acceptable limits [4,5]. But improper placing of capacitors leads to even higher system losses and voltage drops [6].Therefore proper planning and designing is required to place the capacitors. In the recent past, research has concentrated on placing the capacitors in the

Abbreviations WOA, Whale Optimization Algorithm; RDS, Radial Distribution System; BFOA, Bacterial Foraging Optimization Algorithm; MILP, Mixed Integer Linear Programming; MINLP, Mixed Integer Non-Linear Programming; PGS, Plant Growth Simulation; PSO, Particle Swarm Optimization; GA, Genetic Algorithm; FPA, Flower pollination Algorithm; IHA, Improved harmony Algorithm; GSA, Gravitational Search Algorithm; BSOA, Backtracking Search Optimization Algorithm; TLBO, Teaching Learning Based Optimization

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Nomenclature

P_p	real power flow from bus p	V_p	voltage at bus p
Q_p	reactive power flow from bus p	V_{p+1}	voltage at bus $p + 1$
P_{Lp}	real power load connected at bus p	K_i	cost co-efficient in \$/kWh
Q_{Lp}	reactive power load connected at bus p	K_c	cost co-efficient in \$/kVAr
$P_{L(p+1)}$	real power load connected at bus $p + 1$	Q_{pc}	reactive power compensation
$Q_{L(p+1)}$	reactive power load connected at bus $p + 1$	$V_{\min}$	minimum value of bus voltage
$R_{p,p+1}$	resistance connected between the buses p and $p + 1$	$V_{\max}$	maximum value of bus voltage
$X_{p,p+1}$	reactance connected between the buses p and $p + 1$	$P_{\text{Total loss}}$	total power loss in the system

distribution network. Many optimization techniques are proposed to find the optimal size and location of the capacitors in the distribution network.

Few researchers have used classical techniques to obtain optimal placement of capacitors considering only loss reduction as the objective [7,8]. Classical methods have disadvantages such as difficulty in escaping local minima and difficulty to handle discrete control variables [9]. However, research has been carried out by using Mixed Integer Non-Linear Programming and Heuristic approaches as well. Devabalaji et al. have presented Bacterial Foraging Optimization Algorithm (BFOA) to find optimal size and site for capacitor placement [10]. Franco et al. have used Mixed Integer Linear Programming (MILP) technique for placing voltage regulators and capacitors in a distribution network [11]. Oliveira et al. have used Mixed Integer Non-Linear Programming (MINLP) approach to obtain optimum size of the capacitor to further reduce system losses [12]. Plant Growth Simulation (PGS) is another method used for optimal siting of the capacitors for voltage improvement and loss reduction [13]. Prakash et al. have used Particle Swarm Optimization (PSO) method for finding capacitor placement and size [14]. Genetic Algorithm (GA) based approach for capacitor placement is reported in [15]. Sayyad et al. have proposed Mixed Integer Non-Linear Programming (MINLP) for finding location of capacitors to reduce power loss [16]. Shuaib et al. used Gravitational Search Algorithm (GSA) for finding optimal location of capacitors [17]. Backtracking Search Optimization Algorithm (BSOA) is used for optimal allocation of multi-type distributed generators in distribution system for reducing system losses and increasing voltage stability [18]. Niknam et al. [19] presented Teaching Learning Based Optimization (TLBO) approach to find optimal place of automatic voltage regulators in distribution systems. Ali et al. [20] presented Improved Harmony Algorithm (IHA) to find the optimal allocation and sizing of capacitors in distribution network. Abdelaziz et al. [21] presented Flower Pollination Algorithm (FPA) technique for robust tuning of static VAR compensator to mitigate power system oscillations. To find out the optimal place and size of capacitors in radial distribution system Flower Pollination Algorithm is presented in [22]. However the above mentioned algorithms appear to be effective, but they may not guarantee reaching optimal cost value and are difficult to escape from the local minima.

In this work, a new method of optimization based on the behavior of Whales called as Whale Optimization Algorithm (WOA) is applied to find optimal location and size of capacitors in a power distribution network for the first time. It is a nature enthused meta-heuristic optimization algorithm. The purpose of developing such heuristic algorithms is to decrease the search space. The proposed method is tested on standard 34 bus and 85 bus test systems by considering multi objectives-cost reduction, loss minimization and voltage profile improvement. From the literature survey, it is clear that application of WOA has not been discussed so far to solve for capacitor placement in distribution system. This encourages taking up this algorithm for the above said problem. Comparison of the results obtained by the proposed algorithm with those of PSO, PGS, MINLP and BFOA methods reveals that, optimal size and location of capacitors as obtained by the new Whale Optimization Algorithm (WOA) are more effective in cost reduction and maintaining voltage profile.

2. Whale Optimization Algorithm (WOA)

This is a nature enthused meta-heuristic optimization algorithm and it is derived based on the behavior of the humpback whales. Whales are considered as the biggest animal in the world. According to Hof and Van Der Gucht [23], certain cells in the brain of whales are similar to those of human beings. These whales search their food by the special behavior called bubble-net feeding method [24]. This method of searching is based on creating bubbles by encircling or through '9'-shaped path [25].

This behavior of searching is modeled mathematically as two phases [26].

2.1. Searching and encircling prey

Searching prey can be modeled by using Eqs. (1) and (2):

$$D = |C \cdot X_{rand} - X| \tag{1}$$

$$X(t+1) = X_{rand} - A \cdot D \tag{2}$$

where variables A and C are coefficient vectors represented as

$$A = 2 \cdot a \cdot r - a \tag{3}$$

$$C = 2 \cdot r \tag{4}$$

where 'a' is linearly decreasing from 2 to 0 and 'r' is the random number between $[0, 1]$.