Electrical Power and Energy Systems 69 (2015) 441–455

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Optimal allocation of capacitor banks in radial distribution systems for minimization of real power loss and maximization of network savings using bio-inspired optimization algorithms

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ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 13 January 2015
Accepted 31 January 2015
Available online 18 February 2015

Keywords:
Bio-inspired algorithms
Capacitor banks
Real power loss minimization
Network savings maximization
Radial distribution systems

ABSTRACT

In this paper, two new algorithms are implemented to solve optimal placement of capacitors in radial distribution systems in two ways that is, optimal placement of fixed size of capacitor banks (Variable Locations Fixed Capacitor banks-VLFQ) and optimal sizing and placement of capacitors (Variable Locations Variable sizing of Capacitors-VLVQ) for real power loss minimization and network savings maximization. The two bio-inspired algorithms Bat Algorithm (BA) and Cuckoo Search (CS): search for all possible locations in the system along with the different sizes of capacitors, in which the optimal sizes of capacitor are chosen to be standard sizes that are available in the market. To check the feasibility, the proposed algorithms are applied on standard 34 and 85 bus radial distribution systems. And the results are compared with results of other methods like Particle Swarm Optimization (PSO), Harmonic Search (HS), Genetic Algorithm (GA), Artificial Bee Colony (ABC), Teaching Learning Based Optimization (TLBO) and Plant Growth Simulation Algorithm (PGSA), as available in the literature. The proposed approaches are capable of producing high-quality solutions with good performance of convergence. The entire simulation has been developed in MATLAB R2010a software.

Introduction

The analysis of power distribution systems is an important area of research due to the fact that it is the final link between the bulk power system and consumers. However, reactive power flow in a distribution network always cause high power losses. The reactive power support is one of the well-recognized methods for the reduction of power losses together with other benefits; such as loss reduction, power factor correction, voltage profile improvement to the utmost extent under various operating constraints. The shunt capacitor is one of the basic equipment to fulfil these objectives. Therefore, it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives.

Numerous methods for solution to the optimal placement of capacitor with a view to minimizing losses have been suggested in the literature based on both traditional mathematical methods and more recent heuristic approaches. Over the last two decades, the studies on meta-heuristic techniques have shown that the most of the difficulties of classical methods can be eliminated by applying these techniques.

Several heuristic methods have been developed in the last decade for optimal capacitor placement. Prakash et.al presented PSO [1] approach for finding the optimal sizes of capacitors with an objective of reduction of power loss in a radial distribution system. In this paper author used concept of loss sensitivity factors to determine the locations before sizing of capacitors using PSO. Kalyuzhny et al. proposed GA [2] as an optimization tool to place shunt capacitor on distribution system under capacitor switching constraints. Rao et al. [3] presented plant growth simulation algorithm (PGSA) presents two step solution methodology for optimal capacitors placement in radial distribution system with an objective to improve the voltage profile and reduction of power losses. In the first part, determination of optimal locations concept of loss sensitivity factors has been used, later PGSA is used for sizing of capacitors at the optimal locations determined in part one. Sizes of capacitors obtained in PSO & PGSA methods are continues & these are to be rounding off to nearest discrete capacitor sizes available in the market results in changes in the solution: active

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http://dx.doi.org/10.1016/j.ijepes.2015.01.040
0142-0615/

power loss and it may not be optimal. Raju et al. presented direct search algorithm (DSA) [4] to find the optimal size and location of fixed (discrete) and switched capacitors in a radial distribution system to maximize the savings by minimizing the active power loss. DSA uses step by step procedure for finding locations and capacitor sizes resembles the numerical method and it consumes much time to find the optimal solution. Some other heuristic methods such as tabu search [5], the harmony search algorithm [6], ant colony optimization-based algorithm [7] and a simulated annealing technique [8], and Teaching Learning Based Optimization (TLBO) [9] to solve the discrete size capacitor placement optimization problems. A comprehensive survey on the various heuristic optimization techniques applied to determine the optimal capacitor placement and size is presented in [10]. El-Fergany et al., used Artificial Bee Colony (ABC) [11] for optimal capacitor placement problem with an objective to maximize the net savings per year and to improve the voltage profile. In this work, potential location for capacitor connection has been determined by Loss Sensitive Factors (LSF) and voltage sensitive indices (VSI). Later, sizing of capacitor has been done using ABC algorithm. Obtained results are encouraging but, there is no guarantee for locations obtained by LSF & VSI method are optimal or not. The good results reported by others to various engineering optimization problems motivated us to apply novel meta-heuristic Bat and Cuckoo Search algorithms which are proposed by Xin-She-Xang [12,13]. However, from the literature review it is seen that the application of Bat and Cuckoo Search algorithms for optimal capacitor placement problem of distribution system has not been explored in previous works. This motivates the authors to use bio-inspired algorithm such as Bat and Cuckoo Search algorithms to locate optimal position and rating of capacitor in radial distribution system to maximize the annual network savings as an objective by minimizing real power loss. The present work describes Bat and Cuckoo Search algorithms methodologies for optimal capacitor allocation and sizing. Finding both locations and ratings of discrete or fixed size capacitors available in market in the optimal way named as VLFQ-case & finding both locations and ratings continues size of capacitors named as VLVQ case. In this paper, both Bat and Cuckoo Search (CS) optimization algorithms are applied to determine the optimal sizes and locations of capacitors for both VLVQ and VLFQ cases. This problem is formulated as a nonlinear constrained mixed discrete–continuous optimization problem. In order to show the effectiveness of proposed approaches: they have tested on the IEEE 34 and IEEE 85 bus radial distribution networks and the results are compared with the well existing methods available in the literature.

Mathematical modeling of radial distribution system

Two bus model for distribution system analysis

Single line diagram of a two bus radial distribution system is depicted in Fig. 1.

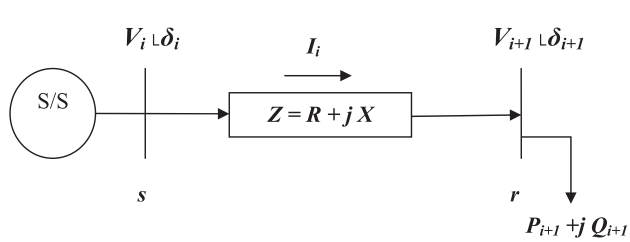

Fig. 1. Two bus of radial distribution system.

$V_i = \lvert V_i\rvert \angle \delta_i$	Sending end voltage
$V_{i+1} = \lvert V_{i+1}\rvert \angle \delta_{i+1}$	Receiving end voltage
$I_i = \lvert I_i\rvert \angle -\theta_i$	Branch current
$Z_i = \lvert Z_i\rvert \angle \emptyset_i$	Branch impedance, where $Z_i = R_i + jX_i$

Form Fig. 1

$$V_{i+1} = V_i - I_i Z_i \tag{1}$$

$$|V_{i+1}|\angle\delta_{i+1} = |V_i|\angle\delta_i - |I_i|\angle - \theta_i * |Z_i|\angle\emptyset_i \tag{2}$$

$$|V_{i+1}|\cos\delta_{i+1} + |V_{i+1}|\sin\delta_{i+1} = |V_i|\cos\delta_i + |V_i|\sin\delta_i - |I_i|(\cos\theta_i - j\sin\theta_i)(R_i^2 + X_i^2) \tag{3}$$

By separating real and imaginary terms

$$|V_{i+1}|\cos\delta_{i+1} = |V_i|\cos\delta_i - |I_i|(R_i\cos\theta_i + X_i\sin\theta_i) \tag{4}$$

$$|V_{i+1}|\sin\delta_{i+1} = |V_i|\sin\delta_i - |I_i|(X_i\cos\theta_i - R_i\sin\theta_i) \tag{5}$$

By squaring and adding Eqs. (4) and (5)

$$|V_{i+1}|^2 = |V_i|^2 - 2|V_i||I_i|\cos\delta_i\{(R_i\cos\theta_i + X_i\sin\theta_i)\} + |I_i|^2\{(R_i^2 + X_i^2)\} - 2|V_i||I_i|\sin\delta_i\{(X_i\cos\theta_i - R_i\sin\theta_i)\} \tag{6}$$

After mathematical treatment Eq. (6) can be written as

$$|V_{i+1}|^2 = |V_i|^2 - 2|V_i||I_i|\{R(\cos(\delta_i - \theta_i)) + X\sin(\delta_i - \theta_i)\} + |I_i|^2\{(R_i^2 + X_i^2)\} \tag{7}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2|V_i||I_i||Z_i|\cos(\delta_i - \theta_i - \emptyset_i) + |I_i|^2\{(R_i^2 + X_i^2)\} \tag{8}$$

Since $\delta_i - \theta_i - \emptyset_i$ is very small hence, $\cos(\delta_i - \theta_i - \emptyset_i) \cong 1$. Because in radial distribution system, voltage angle variations from source bus to the tail end of the feeder are only a few degrees.

Therefore Eq. (8) can be directly written as

$$|V_{i+1}|^2 = |V_i|^2 - 2|V_i||I_i||Z_i| + |I_i|^2\{(R_i^2 + X_i^2)\} \tag{9}$$

$$|V_{i+1}|^2 = [|V_i| - |I_i||Z_i|]^2 \tag{10}$$

$$|V_{i+1}| = |V_i| - |I_i||Z_i| \tag{11}$$

where

$$|I_i| = \frac{(P_i^2 + Q_i^2)^{1/2}}{|V_i|} \tag{12}$$

or it is also written as Eq. (13)

$$|I_i| = \frac{(P_{i+1}^2 + Q_{i+1}^2)^{1/2}}{|V_{i+1}|} \tag{13}$$

$$|V_{i+1}| = |V_i| - \frac{(P_{i+1}^2 + Q_{i+1}^2)^{1/2}}{|V_{i+1}|} * |Z_i| \tag{14}$$

$$|V_{i+1}|^2 = |V_i||V_{i+1}| - (P_{i+1}^2 + Q_{i+1}^2)^{1/2} * (R_i^2 + X_i^2) \tag{15}$$

$$|V_{i+1}|^2 - |V_i||V_{i+1}| + (P_{i+1}^2 + Q_{i+1}^2)^{1/2} * (R_i^2 + X_i^2) = 0 \tag{16}$$

Positive root for Eq. (16)

$$|V_{i+1}| = \frac{|V_i| \pm (|V_i|^2 - 4((P_{i+1}^2 + Q_{i+1}^2)^{1/2})(R_i^2 + X_i^2))^{1/2}}{2} \tag{17}$$

From Eq. (17) receiving end voltage can be directly found.