Electrical Power and Energy Systems 54 (2014) 235–243

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Capacitor placement for net saving maximization and system stability enhancement in distribution networks using artificial bee colony-based approach

Attia A. El-Fergany [a,*], Almoataz Y. Abdelaziz [b]

[a] Department of Electrical Power & Machines, Faculty of Engineering, Zagazig University, P.O. Box 44519, Zagazig, Egypt
[b] Department of Electrical Power & Machines, Faculty of Engineering, Ain Shams University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 12 March 2013
Received in revised form 1 July 2013
Accepted 13 July 2013

Keywords:
Artificial bee colony
Capacitor allocations
Loss reductions
Net saving maximizations
Voltage stability index

ABSTRACT

This manuscript introduces an approach to allocate static capacitors along radial distribution networks using the artificial bee colony algorithm. In general practice the high potential buses for capacitor placement are initially identified using loss sensitivity factors. However, that method has proven less than satisfactory as loss sensitivity factors may not always indicate the appropriate placement. In the proposed approach, the algorithm identifies optimal sizing and placement and takes the final decision for optimum location within the number of buses nominated. The result is enhancement of the overall system stability index and potential achievement of maximum net savings. The overall accuracy and reliability of the approach have been validated and tested on radial distribution systems with differing topologies and of varying sizes and complexities. In the manuscript the results are compared with those obtained using recent heuristic methods and show that the proposed approach is capable of producing high-quality solutions with good performance of convergence, and demonstrated viability.

1. Introduction

Reactive power addition can be beneficial only when correctly applied. Correct application means choosing the correct position and size of the reactive power support. It is not possible to achieve zero losses in a power system, but it is possible to keep them to a minimum [1–3] to reduce the system overall costs. The reactive power support is one of the well-recognized methods for the reduction of power losses together with other benefits; such as increased utilization of equipment, unloading of overloaded system components, and stopping the premature aging of the equipment. However, other alternatives can be used as the network reconfiguration, which can provide the same mentioned benefits. Bear in mind, too many capacitors at the wrong points will increase losses on the lines. However, the minimization of losses does not guarantee the maximization of benefits unless the problem is well-formulated.

Numerous methods for solving this problem with a view to minimizing losses have been suggested in the literature based on both traditional mathematical methods and more recent heuristic approaches. A comprehensive survey of the literature from the last decade focusing on the various heuristic optimization techniques applied to determine the OCP and size is presented in [4]. Several heuristic methods have been developed in the last decade such as tabu search [5], PSO [6,7], the harmony search algorithm [8], ant colony optimization-based algorithm [9,10] and a simulated annealing technique [11], GA [12] and a GA-fuzzy logic algorithm [13] to solve capacitor placement optimization problems.

The bacterial foraging with a PSO algorithm used to determine the optimal placement of capacitors has been introduced in [14], and PGSA has been used for capacitor placement in [15]. More recently, an immune based optimization technique [16], the integration of DE and PS [17], and Big Bang-Big Crunch optimization [18] to obtain the optimum values of shunt capacitors in radial distribution networks have been utilized and employed.

Algorithms for enhancing voltage stability of electrical systems by OCP have been developed [19,20] and a relationship between voltage stability and loss minimization and the concept of maximizing voltage stability through loss minimization were defined and outlined [21,22].

In this article, an ABC-based algorithm is utilized to ascertain the optimal size and select optimum locations of shunt capacitors. High potential buses for capacitor placement are initially identified by the observations of LSF with weak voltage buses. The proposed method improves the voltage profile and reduces system losses in addition to enhancing voltage stability. The method has been

---

* Corresponding author. Tel.: +20 100 5705526.
E-mail addresses: el_fergany@ieee.org (A.A. El-Fergany), almoatazabdelaziz@hotmail.com (A.Y. Abdelaziz).

0142-0615/$ - see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.07.015

Nomenclature

n	total number of lines
N	total number of network buses
P_{Loss}	total network peak active loss
Q_{Loss}	total network peak reactive loss
$\mathrm{VSI}(j)$	voltage stability index of bus j
I_{ij}	current of line i–j
R_{ij}	resistance of line i–j
X_{ij}	reactance of line i–j
$\lvert V_i\rvert$	voltage magnitude of bus i
$\lvert V_j\rvert$	voltage magnitude of bus j
P_j	total effective real power load fed through bus j
Q_j	total effective reactive power fed through bus j
C_e	energy cost
T	time period
P_{La}	total active power loss after compensation
P_{Lb}	total active peak power loss before compensation
C_{Ci}	cost of installation
C_O	capacitor operating cost
C_C	cost of the capacitor purchase
N_B	number of candidate effective buses (that have compensations with values >0)
α	depreciation factor
μ_F	magnifying factor
n_l	number of load buses
P_{Slack}	active power supplied from the slack bus
Q_{Slack}	reactive power supplied from the slack bus
$P_D(i)$	active power demand of load at bus i
$Q_D(i)$	reactive power demand of load at bus i
$P_L(i)$	active power loss at branch j
$Q_L(i)$	reactive power loss at branch j
$Q_C(i)$	amount of reactive power of installed capacitors at bus i
$V_{i,\min}$	lower permissible voltage limit at bus i
$V_{i,\max}$	upper permissible voltage limit at bus i
$Q_{Ci}^{\min}$	lower reactive power limit of compensated bus i
$Q_{Ci}^{\max}$	upper reactive power limit of compensated bus i
S_{li}	actual line flow of line i
S_{li}^{rated}	rated line transfer capacity
$PF_{\min}$	lower limit of overall system power factor at substation (slack bus)
$PF_{\max}$	upper limit of overall system power factor at substation (slack bus)
SN	number of food sources/colony size
D	number of optimization parameters
f_i	cost value of ith solution
fit_i	modified fitness of ith solution
$x_{\max}^j$	upper bounds for the dimension j
$x_{\min}^j$	lower bounds for the dimension j
φ_{ij}	random number in the range $[-1, 1]$
NCN	maximum cycle number
λ_{VC}	penalty function for voltage limit constraint
λ_{PFC}	penalty function for power factor constraint
λ_{LFC}	penalty function for line flow constraint
λ_{CC}	penalty function for maximum total compensation constraint

List of Abbreviations

ABC	artificial bees colony
DE	differential evolution
GA	genetic algorithm
LSF	loss sensitivity factor
OCP	optimal capacitor placement
PGSA	plant growth simulation algorithm
PSO	particle swarm optimization
PS	pattern search
VSI	voltage stability index
HS	heuristic search
EA	evolutionary algorithm
P.U.	per unit
LF	load flow

tested and validated on a variety of radial distribution systems and the detailed results are presented.

Different simplified methods of normal load distribution flow and other special techniques have been proposed [23,24]; these deal mainly with high ratio of R/X in distribution systems. As neither Newton–Raphson nor Gauss–Seidel methods have proven efficient, have experienced difficulties and may not be convergent [25–29]. A method which can find the LF solution of a radial distribution system directly by using topological characteristic of distribution network may overcome the limitations of Newton–Raphson and Gauss–Seidel methods. The advantage of this technique is that there is no problem of convergence with respect to radial networks with high ratio of R/X. The distribution power flow suggested in [24] is used in this study.

2. Voltage stability index

Many different indices have been introduced to evaluate the power systems security level from the point of voltage static stability [30–33]. A new steady state VSI is proposed [33] for identifying the node, which is most sensitive to voltage collapse and expressed in Eq. (1) is utilized in the work. Fig. 1 shows the simple electrical equivalent of the radial distribution system.

$$\mathrm{VSI}(j) = |V_i|^4 - 4\{P_j \cdot X_{ij} - Q_j \cdot R_{ij}\}^2 - 4\{P_j \cdot R_{ij} + Q_j \cdot X_{ij}\}.|V_i|^2 \qquad (1)$$

For stable the operation of the radial distribution networks, VSI $(j) \geqslant 0$. The node, at which the value of the VSI has lower value, is more sensitive to collapse. The node with the smallest VSI is the weakest node and the voltage collapse phenomenon will start from that node. Therefore, to avoid the possibilities of voltage collapse, the VSI of nodes should be maximized.

3. Problem and objective function formulation

The objective of capacitor placement in the distribution system is to maximize the peak active power loss reduction, reduce capacitor costs and enhance the system static stability subject to specific operating constraints. The objective function is mathematically formulated as,

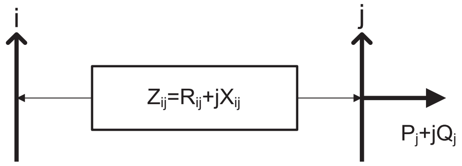

Fig. 1. Line *i*–*j* power system model.