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Optimal integration of shunt capacitor banks in distribution networks for assessment of techno-economic asset☆

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A B S T R A C T

This article presents optimal incorporation of shunt capacitor banks in distribution feeders for the purpose of reduction of power loss, total annual expenses and voltage deviations. Additionally, it improves the voltage level, power factor and voltage stability of the network. To attain these proposed goals, a new multi-objective function has been formulated subjected to some operating constraints. This problem has been solved through Modified Gbest-guided Artificial Bee Colony (MGABC) meta-heuristic optimization technique. This proposed methodology is divided into two parts. In first part, the sensitivity buses are determined using Loss Sensitivity Factor (LSF) approach. In second, the optimization algorithm identifies the optimal buses from derived sensitive buses along with optimal size of shunt capacitors. This proposed methodology is implemented on standard 34-bus and 118-bus distribution feeders. In addition, the achieved numerical outcomes have been compared to the various intelligent approaches for showing the viability and effectiveness of the proposed approach.

1. Introduction

Optimal Capacitor Placement (OCP) in distribution network is more essential and effective for power loss reduction [1–3], power factor improvement and voltage profile enhancement [4,5]. In distribution system there are two types of losses; active power loss and reactive power loss. Such power losses mainly depend on current flowing through the distribution lines. In OCP problem, reactive power compensation will be useful only when optimum location and rating of shunt capacitors are selected. An improper location and size selection may create problem, which may increase power loss and deteriorate the voltage magnitude to unacceptable limits. Hence, it is necessary for the distribution system utilities to optimize their operation by reducing the power loss and enhancing the voltage level of the buses. In past, many researchers have put their extensive effort for OCP in the distribution systems. Neagle and Samson [1] were the first to present placement of shunt capacitors in distribution feeder for power loss reduction. They formulated the problem and solved it analytically. In [2,3], fixed and switched capacitors have been integrated in the distribution networks at optimal allocation for power loss minimization. They developed a generalized procedure for optimizing an OCP problem which is associated with the net savings.

The author's contributions in this work are as follows:

- Gbest-guided Artificial Bee Colony (GABC) algorithm has been modified for improving the performance and solution quality of the problem.

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Nomenclature

$\cos\phi$	Power factor
$\cos\phi_{\min}$ & $\cos\phi_{\max}$	Minimum and maximum value of power factor
F_{ij}	Initial food source location
fit_i	Fitness value of every iteration
$F_{new,ij}$	New food source solution set
$iter$	Iteration
I_{ij}^{rated}	Rated value of current across ij branch
I_{ij}	Flow of current across ij branch
IVS_j	IVS value of jth bus
K_j^c	Capacitor installation cost (\$/kVAr)
K_{PL}	Power loss constant and its value is 0.06 kWh
l	Load level
$Max\ iter$	Maximum number of iterations
NB	Number of Buses
nc	Number of capacitors
$norm\_voltage[i]$	Normalized voltage of bus i
P_{ij}	Flow of active power through i-j bus
P_{TLoss}	Total active power loss of the network (kW)
$P_{prob,i}$	Probability of food source
$P_{mod,i}$	Modified probability of food source
$P_{ij(loss)}$	Active power loss across i-j bus (kW)
P_j^F & Q_j^F	Real and reactive power flow behind bus j
P_i^L & Q_i^L	Total active and reactive power load of the feeder
$P_{lineloss[ij]}$ & $Q_{lineloss[ij]}$	Active and reactive power loss across i-j bus
$P_j^F[eff]$ & $Q_j^F[eff]$	Effective active & reactive power supply behind bus j
P_{jL} & Q_{jL}	Active and reactive load of j^{th} bus
Q_j^c	Size of capacitor (kVAr)
Q_{ij}	Flow of reactive power through i-j bus
$Q_{ij(loss)}$	Reactive power loss of ij branch (kVar)
R_{ij}	Branch resistance between ith and jth bus
S_B	Set of all buses
T_d	Time duration of load levels to operate
$U_{deviation}$	Total voltage deviation
U_i	Sending end voltage at ith bus
U_j	Receiving end voltage at jth bus
U_{min} & U_{max}	Minimum and maximum bus voltage limit (p.u.)
$w1$, $w2$ and $w3$	Weighting factors to normalize the fitness function
X_{ij}	Branch reactance between ith and jth bus
ϕ_{ij}	Random number [0 1]

- A new multi-objective function is formulated through weighting factor approach by combining power loss, total cost and voltage deviation.

The author's work deals with the following points:

- Identification of optimal buses and sizes of shunt capacitors in distribution systems via proposed MGABC algorithm and satisfying all essential operating constraints.
- Analyzing the impact on power loss and voltage magnitude of each bus after OCP at different load levels.
- Impact on Index of Voltage Stability (IVS) and voltage deviation has been examined before and after OCP.
- Evaluation of total cost of the network for compensated and uncompensated systems at different load levels.

The rest of the paper is organized as follows: Section 2 represents the literature review on OCP problem. Section 3 presents the problem formulation which includes objective function along with some operating constraints. Section 4 defines LSF approach and their steps for implementation. Sections 5 and 6 describe IVS and voltage deviation respectively. Permanent and switchable capacitors are described in Section 7. Brief overview of proposed MGABC optimization algorithm and its implementation procedure for solving OCP problem are indicated in Section 8. Discussions on simulation and numerical results for both test systems are presented in Section 9. Finally, the conclusions and direction of future work is drawn in Section 10.

2. Literature review

In the last few decades, various heuristic and meta-heuristic techniques have been implemented [4–19] for solving capacitor installation problem. In [4], a new methodology has been introduced for shunt capacitor placement in distribution feeders. The capacitor locations and ratings are found through Power Loss Index (PLI) approach and Differential Evaluation (DE) based evolutionary optimization algorithm respectively. A Cuckoo Search Algorithm (CSA) has been implemented in [5] to solve OCP task for power loss reduction and voltage profile enhancement at different load levels. A Tabu Search (TS) heuristic technique has been presented for solving shunt capacitors installation problem [6]. The combination of LSF approach and Particle Swarm Optimization (PSO) algorithm have been reported in [7,8] for shunt capacitor installation in distribution systems. In [9], PSO algorithm has been modified and implemented for identifying the optimal positions as well as ratings of shunt capacitors. A sensitivity based approach along with Ant Colony Optimization (ACO) algorithm has been demonstrated in [10] for determining proper allocations and sizes of the shunt capacitors. Flower Pollination Algorithm (FPA) [11] and Improved Harmony Algorithm (IHA) [12] has been used for minimization of total cost of the network by optimal integration of shunt capacitors. In [13], a heuristic search technique was utilized to get the optimal locations and sizes of shunt capacitors for achieving overall loss reduction and voltage profile enhancement. In [14], Artificial Bee Colony (ABC) algorithm has been employed to maximize the power loss reduction and cost saving of the network by incorporating shunt capacitors. A two stage method is introduced in [15] for OCP in distribution networks to achieve voltage profile improvement and power loss saving. In [16], fuzzy based real coded GA has been applied for OCP task to reduce the power

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