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Optimum placement of shunt capacitors in a radial distribution system for substation power factor improvement using fuzzy GA method

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ABSTRACT

In this work a combination of fuzzy multiobjective and genetic algorithm (GA) based approach is proposed for optimal shunt capacitor placement to improve the substation power factor near unity, reduce the real power loss, and reduce the burden on the substation and to improve the voltage profile of the distribution network. In order to obtain best nodes for capacitor placement, a sensitivity index based on real power loss reduction and voltage profile improvement is considered. In the present work, an attempt is made to make reactive current component drawn by distribution network through substation is nearly zero such that power factor at the substation will be near unity. A fuzzy multiobjective function is formed considering substation reactive current component reduction, real power loss reduction, branch current constraint limit, minimum and maximum voltage limit satisfaction. The fuzzy multiobjective function is maximized using GA for obtaining the optimum sizing of fixed and switched shunt capacitors. Simulation results are shown to demonstrate the advantage of the proposed method compared to optimal shunt capacitor placement based on annual energy savings method.

Introduction

Shunt capacitors usage is a common practice to supply reactive power in the distribution networks. Installation of shunt capacitors reduces power losses, improves the power factor and feeder voltage profile. Therefore it is essential to find optimal location and sizes of capacitors for gaining maximum benefits by the shunt capacitor installation. Ng et al. [1] classified the capacitor placement techniques available in the literature into four categories. They are analytical, numerical programming, heuristic and artificial intelligence based techniques. In the early literature many researchers proposed calculus based analytical techniques for capacitor placement solution [2–6]. Initially, methods are developed based on the assumption of uniform conductor size and loading throughout the feeder and later they are extended for different conductor sizes and nonuniform loading. With the development of powerful computational techniques numerical methods were developed for the selection of optimal nodes and sizing of capacitors considering all the operational constraints [7–13]. In order to reduce the large search space required by the numerical methods many authors have proposed heuristic methods to obtain nearly optimal solution for capacitor placement problem [14–18]. For the last two decades artificial intelligence techniques are widely used for identifying optimal locations and sizing of capacitors, out of them fuzzy logic, genetic algorithms are more popular. Ng et al. [19], Mekhamer et al. [20], Masoum et al. [21], Shi and Liu [22] and Bhattacharya and Goswami [23] used fuzzy set theory based on human experience and intuition for identification of optimal nodes for capacitor placement and for optimal capacitor sizing, they have used numerical methods and heuristic methods. Boone and Chiang [24], Iba [25], Sundharajan and Pahwa [26], Delfanti et al. [27], Das [28], Malik et al. [29] and Swarnakar et al. [30] applied genetic algorithms for optimal allocation of capacitors. Gallego et al. [31], De Souza et al. [32], Hsiao et al. [33], Das [34], and Abul'Wafa [35] have used combination of fuzzy logic and genetic algorithms for optimal allocation of capacitors in distribution systems. In the recent years many nature inspired based artificial intelligence techniques are developed and used for optimal capacitor allocation problem. Huang et al. [36] have proposed two stage immune algorithm based multi objective optimization approach for solving shunt capacitor placement problem. Rao [37] has used fuzzy and plant growth simulation algorithm to determine optimal locations and size of the capacitor to improve the voltage profile and reduce the active power losses. Singh and Rao [38] have proposed a particle swarm optimization based algorithm for obtaining the optimal size and locations of the capacitors utilizing the daily load curve. Ziari et al. [39] have proposed a

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Nomenclature

I_i^{ac}	current magnitude through *i*th branch after capacitor placement
IC_i	maximum current carrying capacity of *i*th branch
NB	total number of nodes of the distribution system
F	fuzzy multiobjective function
P_{S_i}	power injected at substation before capacitor placement at *i*th load level
$P_{S_i}^{QC}$	power injected at substation after capacitor placement at *i*th load level
QC_j	total capacity of shunt capacitors installed at *j*th rank node
K_e	energy cost in $/kW h
C_C	cost of capacitor in $/kVAr
C_I	capacitor installation cost in $/location
CRF	capital recovery factor
NL	total number of load levels
NCL	total number of capacitor installation locations
T_i	total number of hours of *i*th load level duration in one year
S_{CP}	annual economical savings due to shunt capacitor placement

modified discrete particle swarm optimization technique for the determination of rating and locations of fixed and switched capacitors. El-Fergany et al. [40] have proposed artificial bee colony based approach for allocation of static capacitors along the radial feeders of the distribution system. Hung et al. [41] classified devices capable of supplying reactive power only as type-2 kind of distributed generation. Aman et al. [42] presented a literature survey on optimal shunt capacitor placement.

From the above literature survey, it can be seen that the capacitor placement problem is aimed to obtain optimal locations and sizing of capacitors to reduce the active power losses, to increase feeder capacity and to improve the voltage profile of the radial distribution system. In the present work a new sensitivity analysis is proposed to find suitable nodes for the capacitor placement problem. For obtaining optimum sizing of capacitors at the optimum locations identified the objectives of minimizing reactive current drawn by the distribution network from the grid through substation, real power loss reduction, feeder capacity improvement and voltage profile improvement are considered to improve the substation power factor, nearer to unity. Since all the objectives considered are non-commensurable in nature, the conventional approaches that optimizes a single objective function are not suitable for this problem. Therefore the fuzzy approach is adopted for considering all the multiple objectives simultaneously.

The conventional calculus based techniques mainly depends upon the existence of derivatives of the single objective function and may lead toward the local optimum solution. The actual search space in majority of the practical cases is associated with many discontinuous functions and hence the conventional optimization methods are not suitable for finding optimal solutions for non differentiable multiobjective functions. Genetic Algorithms (GA) are probabilistic search techniques based on natural selection and genetics. The advantage of GA compared to other conventional techniques is it works with binary coding of parameters rather than parameters themselves and hence it is more efficient optimization technique for non differentiable multiobjective functions consisting both discrete and continuous variables. GA proceeds in the direction of maximization of fitness function in the selected multi dimensional search space and hence the solution proceeds toward global optimum. Hence for the present capacitor placement problem a genetic algorithm based fuzzy multiobjective approach is used for optimum sizing of fixed and switched capacitors.

The main motivation of this work is that the distribution network should not draw reactive power from the grid. Shunt capacitors must meet the total reactive power load demand and reactive power loss of the distribution network. Therefore, in this paper, the approach is to make the substation power factor near unity, i.e. drawing negligible reactive power from the grid.

Sensitivity analysis for the placement of capacitors

In the present analysis, a new sensitivity index is used for the placement of capacitors in a distribution network. In the sensitivity analysis the load flow solutions are obtained by compensating the total reactive load at every node and from the load flow solutions the active power loss reduction and maximum node voltage increment are calculated for all nodes of distribution system.

Let us define a sensitivity index,

$$S_k = LSI_k \times VSI_k \quad (1)$$

where

S_k = Sensitivity index of *k*th node due to total reactive load compensation.

LSI_k = Loss sensitivity index of *k*th node due to total reactive load compensation.

VSI_k = Voltage sensitivity index of *k*th node due to total reactive load compensation.

The loss sensitivity index can be expressed mathematically as follows:

$$LSI_k = \frac{PLR_k - PLR_{\min}}{PLR_{\max} - PLR_{\min}} \quad (2)$$

$$PLR_k = PLB - PL_k \quad (3)$$

where

PLB = Real power loss without shunt capacitor compensation.

PL_k = Real power loss due to total reactive load compensation at *k*th node.

PLR_k = Real power loss reduction due to total reactive load compensation at *k*th node.

$PLR_{\min}$ = Minimum Real power loss reduction.

$PLR_{\max}$ = Maximum Real power loss reduction.

The voltage sensitivity index can be expressed mathematically as follows:

$$VSI_k = \frac{DVM_k - DVM_{\min}}{DVM_{\max} - DVM_{\min}} \quad (4)$$

$$DVM_k = \max|\widetilde{V}_{i,k}^{ac} - \widetilde{V}_{i,k}^{bc}| \quad (5)$$

where

DVM_k = Maximum node voltage increment due to total reactive load compensation at *k*th node.

$DVM_{\min}$ = Minimum of Maximum node voltage improvement.

$DVM_{\max}$ = Maximum of Maximum node voltage improvement.

$\widetilde{V}_{i,k}^{bc}$ = Voltage at *i*th node before capacitor placement at *k*th node.

$\widetilde{V}_{i,k}^{ac}$ = Voltage at *i*th node after capacitor placement at *k*th node.