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Full Length Article

Incorporation of distributed generation and shunt capacitor in radial distribution system for techno-economic benefits

Mukul Dixit *, Prasanta Kundu, Hitesh R. Jariwala

Department of Electrical Engineering, S. V. National Institute of Technology, Surat, India

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A B S T R A C T

This paper addresses an incorporation of Distributed Generation (DG) and shunt capacitor in a distribution system simultaneously for minimizing active power loss. For this purpose, the Index Vector Method (IVM) and Power Loss Index (PLI) approach is utilized to determine the suitable position/location of DGs and shunt capacitors. However, the sizes/capacities of these are determined through population based Gbest-guided Artificial Bee Colony (GABC) meta-heuristic optimization algorithm.

The various costs such as purchase active power from grid, DG installation, capacitor installation, DG Operation and Maintenance (O&M) are evaluated at two different load scenarios. In addition to that, technical and economical analyses are examined for various combinations of DGs and shunt capacitors. The proposed methodology is successfully demonstrated on 33-bus and 85-bus radial networks and the obtained numerical outcomes validate the suitability, importance and effectiveness to identify locations as well as sizes of DGs and shunt capacitors.

1. Introduction

In electrical power system distribution system is a more complex network and having a higher power loss as compared to transmission network due to high *R/X* ratio. Reduction of such power loss is a major challenge in front of distribution companies. The major outlooks for power loss reduction are Dispersed Generation (DG) placement, capacitor placement and system re-configuration. In the last few years, DG placement has become a very renowned research area. After incorporating DG into a system, it provides several potential benefits such as voltage level enhancement, reduction of power loss and improve system stability [1,2]. Combination of both DG and shunt capacitor can play important role for reducing power loss and enhance voltage level to a great extent, if these are properly located with optimum size.

In last few years, the researchers have been utilized various meta-heuristic based intelligent techniques [3–10] for solving DG and shunt capacitor placement problem. In [3], presented an Evolutionary Programming (EP) approach for power loss and THD minimization through optimal placement of DG units. Ref [4], presented an optimal installation of DGs in a distribution system using Artificial Bee Colony (ABC) algorithm. In [5], multi-objective based capacitor placement problem has been solved by Heuristic Search (HS) approach. A Cuckoo Search Algorithm (CSA) demonstrated for reducing power loss and improved voltage level by incorporating shunt capacitor at optimal location [6]. In [7,8], a multi-objective function has been formulated for the purpose of incorporating multiple DG units at multiple locations through Backtracking Search Algorithm (BSA). Ref [9], presented an Artificial Bee Colony (ABC) algorithm for determining exact positions and ratings of shunt capacitors for the purpose of power loss minimization and increment in cost savings. Tabu search (TS) [10] and Immune optimization (IO) [11] Algorithm has been utilized to reduce active power loss of a network through optimal capacitor placement. Ref [12], suggested a fuzzy Shuffled Frog Leaping Algorithm (SFLA) to solve multi objective network re-configuration problem in the availability of reactive power support compensators. In [13], GA has been employed for determining optimal allocation and size of fixed and switched capacitors under load uncertainty. In present work, the allocations/positions of DGs and capacitors are found through two different approaches while the optimal sizes/capacities are determined using GABC algorithm. This methodology is new for solving present problem. Therefore, this method is selected as a preferred method.

The author's contribution in this work, are as follows:

- Implementation of IVM and PLI approach for identifying DG and shunt capacitor location respectively.

* Corresponding author.
E-mail address: d13el002@eed.svnit.ac.in (M. Dixit).

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Nomenclature

$\cos\varphi$	power factor
$DG_{cap,i}$	DG capacity (kVA)
$I_p(m)$	real part of current in mth segment
$I_q(m)$	imaginary part of current in mth segment
$I_{i,i+1}$	current value between ith and $(i+1)$th bus
$I_{i,i+1}^{rated}$	rated value of current between ith and $(i+1)$th bus
$infR$	inflation rate (9%)
$intR$	interest rate (12.50%)
K_c^{inst}	capacitor purchase cost ($/kVar)
K_c^f	capacitor fixed cost (1000 $)
K_{DG}^{inst}	purchase cost of DG (400,000 $/MW)
K_{DG}^{OM}	O&M cost of DG (36 $/MW h)
$LR(i)$	loss reduction value of ith bus
LR_{min}	minimum loss reduction value
LR_{max}	maximum loss reduction value
ndg	number of DG
$ncap$	number of capacitor
P_{DG}	real power of DG (kW)
P_i	active power flow from ith bus
$P_{L,i+1}$	active load of $(i+1)$th bus (kW)
Q_C	capacitive compensation (kVar)
$Q(i)$	reactive load at ith bus
Q_i	reactive power flow from ith bus
$Q_{c,i}$	capacitor rating (kVar)
Q_{DG}	reactive power of DG (kVar)
$Q_{L,i+1}$	reactive load of $(i+1)$th bus
$R_{i,i+1}$	branch resistance between bus ith and $(i+1)$th
S_B	set of all buses
S_{DG}	total DG capacity
S_{Load}	total kVA load of the system
$Total\ Q$	total reactive load of a network (kVar)
TS_c	purchase active power cost from grid
$V_{deviation}$	voltage deviation
V_i	voltage of ith bus (pu)
V_i^{min}	minimum voltage of ith bus (pu)
V_i^{max}	maximum Voltage of ith bus (pu)
V_{rated}	rated voltage 1 p.u.
$VSI_{(i+1)}$	voltage stability index of $(i+1)$th bus
$X_{i,i+1}$	branch reactance between bus ith and $(i+1)$th

Abbreviations

ABC	Artificial Bee Colony
DG	Distributed Generation
GA	Genetic Algorithm
GABC	Gbest-guided Artificial Bee Colony
IVM	Index Vector Method
LR	Loss Reduction
NB	Number of Buses
O&M	Operation and Maintenance
PL	Penetration level
PLI	Power Loss Index
VSI	Voltage Stability Index
THD	Total Harmonic Distortion

- GABC optimization algorithm is employed to determine optimal sizes/capacities of DGs and shunt capacitors simultaneously for total real power loss reduction.
- Impact on voltage level, VSI and voltage deviation have been analyzed after incorporating DG and shunt capacitor at different load levels.
- Evaluation of various costs such as purchase active power from grid, DG and shunt capacitor Installation cost, DG O&M cost at different load levels.

2. Power Loss Index (PLI)

This approach is implemented for identifying suitable buses for placement of shunt capacitor and it is also helpful for shrinking the search space during optimization procedure. In addition, power flow calculations are required to calculate the loss reduction (LR) values by providing reactive power compensation at each bus, which is equal to a total reactive load of a network. At a time one bus is considered [5]. The relation for evaluating PLI value of ith bus is formulated using (1).

$$PLI(i) = \frac{LR(i) - LR_{min}}{LR_{\max} - LR_{\min}} \tag{1}$$

Those buses which are having higher PLI values and system voltage below 0.95 pu are chosen as candidature buses for capacitor installation. These are the following steps for implementation of PLI approach to identify candidate buses for capacitor placement.

Step 1: Run load flow and compute real power loss.
Step 2: Provide reactive power compensation across each bus, which is equal to the total system reactive load of a network and then execute load flow program and evaluate system real power loss for all the buses except slack bus and store the values.
Step 3: Calculate LR = (Base case system active power loss – system active power loss obtained for each bus compensation) and store.
Step 4: Determine maximum and minimum LR. Then evaluate PLI values using (1). Sort these PLI values in descending order. Those buses which are having higher PLI values and lower voltage under 95% are preferred as most suitable buses for placement of capacitor.

3. Index Vector Method (IVM)

This method is being utilized for incorporating DG units in a distribution system and also very useful for reducing the search space during optimization procedure. The base case load flow program of considered test network is required for evaluating necessary component like imaginary and real part of current in each feeder segment to formulate IVM approach [14]. Based on the IVM values, this method identifies candidate buses for DG placement. The expression for computing IVM values of ith bus may be expressed as

$$IVM(i) = \frac{1}{V_i^2} + \frac{I_q(m)}{I_p(m)} + \frac{Q(i)}{total\ Q} \tag{2}$$

The steps for implementation of IVM approach are as follows.

Step 1: First of all, run base case load flow program.
Step 2: Store the values of voltage for every bus, real and imaginary component of current across each branch.
Step 3: Calculate index vector values of all the buses using (2) and sort these values in decreasing mode. Then, evaluate normalized voltage $norm(i) = V_i/0.95$ @ all buses.
Step 4: At last, those buses which are having higher IVM values and lower normalized voltage under 1.01 are chosen as optimal locations/positions for DG installation.

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