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Enhancement of loading capacity of distribution system through distributed generator placement considering techno-economic benefits with load growth

Khyati D. Mistry, Ranjit Roy *

Department of Electrical Engineering, S.V. National Institute of Technology, Surat 395007, Gujarat, India

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ABSTRACT

Load growth in a system is a natural phenomenon. With the increase in load demand, system power loss and voltage drop increases. Distributed generators (DGs) are one of the best solutions to cope up with the load growth if they are allocated appropriately in the distribution system. In this work, optimal size and location of multiple DGs are found to cater the incremental load on the system and minimization of power loss without violating system constraints. For this a predetermined annual load growth up to five years is considered with voltage regulation as a constraint. The particle swarm optimization with constriction factor approach is applied to determine the optimum size and location with multiple DGs. To see the effect of load growth on system, 33-node IEEE standard test case is considered. It is observed that with the penetration of multiple number of DGs in distribution system, there is great improvement in several distribution system parameters. Moreover, the loading capacity of distribution system is enhanced through DG placement and its techno-economic benefits are also established.

1. Introduction

Steady increase in energy demand on distribution system due to natural growth of a service territory or through stimulation of energy market is a big challenge to planning engineers so that the system is adaptable without violating service quality. Load growth on system results into either extra expenditure made towards the addition of new substation or expanding the existing substation capacity. Due to power system deregulation and environmental concerns as well as technological advancements, the Disco (Distribution Company) planners are forced to investigate expansion planning through alternatives such as distributed generation (DG).

Incorporation of distributed generation is an important aspect in distribution system in view of loss reduction, reduction in operating costs and improvement in voltage profile. It was estimated that distribution systems cause a loss of about 5–13% of the total power generated [1]. The cost due to energy losses is a major part of the electricity bill. Restructuring in power systems encourage the penetration of more and more DG at distribution level.

Distributed generator or decentralized generation is a small power generator ranging from few kilowatts to few megawatts. It can operate stand-alone or in correlation with distribution network but is not dispatchable by a central operator. To maximize DG benefits, DG must be of appropriate size, to be placed at the appropriate location and in appropriate number. Inappropriate capacity of DG may cause higher system power loss. This is because the reverse power flows from larger DG units to the source which results into instability of the system.

An algorithm [2] was developed for the connection of multiple DGs in distribution networks according to the type of consumer. The author has considered different type of DGs with various sizes and also considered different types of voltage dependent load over several years. A multi-objective approach to a distribution network planning process was proposed in [3]. It has considered DG placement for the planning of distribution network and to study the impact of the position and size of generation units on network losses and short circuit level. The algorithm used are multi objective evolutionary PSO, multi objective Tabu search and Genetic algorithm for DG sizing and location. In [4], a comprehensive planning model for distribution system is formulated which considers several objective function (economical, environmental, and technical). A framework is presented in [5] to solve the problem of multistage distribution system expansion planning in which installation and/or reinforcement of substations, feeders and distribution generation units are taken into consideration. A multistage distribution network expansion planning problem in the presence of distributed generation in a multi-objective optimization framework is carried out in [6]. The proposed model simultaneously optimizes two objectives: minimization of investment and operation costs

* Corresponding author. Tel.: +91 9904402937; fax: +91 261 2227334.
E-mail address: rr@eed.svnit.ac.in (R. Roy).

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Nomenclature

NB	total number of nodes
LN1	total number of branches
jj	branch number
$r_{(jj)}$	resistance of branch jj
$x_{(jj)}$	reactance of branch jj
$I_{(jj)}$	current flowing through branch jj
$V_{(m1)}$	voltage of node $m1$
$V_{(m2)}$	voltage of node $m2$
$P_{(m2)}$	total real power load fed through node $m2$
$Q_{(m2)}$	total reactive power load fed through node $m2$
$LP_{(jj)}$	real power loss in branch jj
$LQ_{(jj)}$	reactive power loss in branch jj
δ_{m2}	phase angle of voltage $V_{(m2)}$
IR(jj)	receiving end node of branch jj
IS(jj)	sending end node of branch jj
IL(i)	load current of branch i
IC(i)	charging current of branch i
Y(i)	admittance of branch i
PL(i)	real load power at branch i
QL(i)	reactive power at branch i
V_i^{min}	minimum voltage limit of node i
V_i^{max}	maximum voltage limit of node i
I_{jj}^{max}	maximum current capacity of branch jj
VSI_{mini}	minimum voltage stability index
$VSI_{(i)}$	voltage stability index of node i
P_i	real power injection at node i
P_{DGi}	real power generation at node i
P_{Di}	real power demanded at that node i

and maximization of reliability index. A study was carried out in [7] to determine appropriate DG sites for distribution systems. A multi-objective function is introduced for the optimal operation of a distribution system with distributed generator unit using a goal programming technique in [8]. A multi-objective index based approach determining the size and location of multi distributed generation (multi-DG) units in distribution systems with different load model is introduced in [9]. The proposed multi objective function optimizes the short circuit level parameter to represent the protective device requirements with the help of particle swarm optimization (PSO). A multi objective optimization technique is proposed for the siting and sizing of renewable electricity generators [10]. The objective function consists of minimization of costs, emission and losses of distribution system and improvement of voltage profile.

A novel approach based on cuckoo search (CS) [11] is applied for optimal distributed generation (DG) allocation to reduce power loss of the distribution network. Dynamic programming approach is developed in [12] to determine the optimal feeder routes and branch conductor sizes by simultaneous optimization of cost and reliability for distribution system planning. A Modified Teaching–Learning Based Optimization (MTLBO) algorithm is proposed in [13] to determine the optimal placement and size of distributed generation (DG) units in distribution systems to minimize real power losses. Combined Genetic algorithm (GA)/particle swarm optimization (PSO) is presented in [14] for optimal location and sizing of DG on distribution system to minimize power losses. Three algorithms were developed for obtaining the optimal feeder path and the optimal location of substation on minimum loss criterion for distribution system planning in [15]. Heuristic rules are incorporated in the algorithm. Two step approaches is presented for optimal multi conductor size selection in planning of radial distribution system in [16]. Initially using economical criteria, economical conductor size options for each feeder segment are selected then, to determine optimal options, a partial enumeration method has been developed. A simple search approach for determining optimal sizing and optimal placement of distributed generators using N–R method of load flow study is developed in [17] to reduce cost and losses. The ENS (energy not served) index is calculated for every section of the distribution network to allocate DG resources to improve network reliability, power quality and minimizing power losses in [18]. A new algorithm for distributed generator (DG) placement and sizing of distribution systems based on power stability index (PSI) was proposed in [19] to visualize the impact of DG on system losses, voltage profile and voltage stability. Mono and multi-objective approaches for electrical distribution network design problems, i.e., static expansion planning are solved using PSO in [20]. The network planning involves optimization of both network topology and branch conductor sizes. Optimal size and site were found out in [21] to minimize DG's investment and operating costs. A model for distribution system planning based on Genetic algorithm, where DG integration is considered together with conventional alternatives for expansion in [22,23]. Incorporation of DG in distribution system planning problem is presented in [24] to minimize capital cost for network upgrading, operation and maintenance costs and cost of losses for handling the load growth for the planning horizon. Table 1 shows the review of literature on distribution system planning and DG integration in distribution system.

In the present work, a simple algorithm is used to find out the DG size and site for catering the load on the feeders without violating the voltage limits of the feeder. Here the objective function is to minimize the active power loss. For this study a predetermined annual load growth is considered for five years.

The main contribution of the work deals with the following issues with load growth:

(1) Increase in load capacity of the distribution system.
(2) Impact of multiple number of DG with load growth in a distribution network on active power losses.
(3) Impact of multiple number of DG on reactive power losses.
(4) Impact of DG on purchased cost of energy from the transmission network.
(5) Impact of DG on total cost of energy with load growth.
(6) Impact of DG on voltage profile.
(7) Impact of DG on voltage stability index.
(8) Minimizing voltage deviation.

In the following sections, impact of load growth on system parameters are presented in Section 2, mathematical formulation of problem is explained in Section 3, Section 4 briefly describes the load flow technique adopted, and techno-economic evaluation of DG placement in distribution system is illustrated in Section 5. Sections 6 and 7 describe the assumption made for DG placement and cost of DG placement respectively, computation procedure for multiple DG placements is given in Section 8, Particle swarm optimization with constriction factor approach is illustrated in Section 9 and a case study is reported in Section 10. Section 11 discuses the outcome of this work and finally, the conclusion of the paper is summarized in Section 12.