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Comparison of optimal DG allocation methods in radial distribution systems based on sensitivity approaches

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ABSTRACT

Integration of renewable energy based distributed generation (DG) units provides potential benefits to conventional distribution systems. The power injections from renewable DG units located close to the load centers provide an opportunity for system voltage support, reduction in energy losses, and reliability improvement. Therefore, the location of DG units should be carefully determined with the consideration of different planning incentives. This paper presents a comparison of novel, combined loss sensitivity, index vector, and voltage sensitivity index methods for optimal location and sizing of distributed generation (DG) in a distribution network. The main contribution of the paper is: (i) location of DGs based on existing sensitivity methods, (ii) proposing combined power loss sensitivity based method for DG location, (iii) modified Novel method for DG location, (iv) comparison of sensitivity methods for DG location and their size calculations, and (v) cost of losses and determining cost of power obtained from DGs and the comparison of methods at unity and lagging power factors. The results show the importance of installing the suitable size of DG at the suitable location. The results are obtained with all sensitivity based methods on the IEEE 33-bus and 69-bus systems.

1. Introduction

Distributed power generation (DG) is electricity production that is on-site and refers to small generating units installed near local loads or load centers to avoid the need of the network expansions in order to cover new load areas or to support the increased energy transfer which would be necessary for satisfying consumers demand. DG can be an alternative for residential, commercial, and industrial applications. However, distributed generation can be defined in a variety of ways as reported in the literature. The Electric Power Research Institute (EPRI) defines distributed generation as generation from 'a few kilowatts up to 50 MW [1]. International Energy Agency (IEA) defines distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distributed level voltages. The International Conference on large High Voltage Electric Systems (CIGRE) defines DG as smaller than 50–100 MW [1]. The share of DGs in power system is increasing worldwide and their contribution in the future power system is expected to be even more [2]. There are many reasons behind the increasingly widespread use of DG deferring the Transmission and Distribution (T&D) costs, good efficiencies especially in cogeneration and in combined cycles, creating opportunities for new utilities in the power generation sector, and provides a flexible way to choose a wide range of combinations of cost and reliability. DG impacts different parameters of a power system, comprising voltage profile, line losses, and short circuit current, amount of injected harmonic, and system reliability and stability. The parameters have to be appropriately investigated prior to installation of DG units. The problem of allocating DG units to optimal places and also their sizing is of higher priority amongst all issues. However, installation of DG units in non-optimal places may results in an increase in system losses and a bad effect on voltage profile and other parameters which may lead to a growth of costs, and consequently an opposite effect on what is expected. Therefore, DG should be allocated in an optimal way to maximize the system efficiency. Studies also show that if the DG units are connected at non-optimal locations or have non-optimal sizes, the system losses may increase. To analyze the distributed energy resources (DER) impacts, different types of 'generator groups' can be considered in [3]. Many authors have proposed sensitivity based approaches and optimization based methods for optimal location and sizing of DGs in distribution systems.

The impact of DG on radial distribution network is explained i.e., voltage support, loss reduction, and distribution capacity release and power quality issues in [4]. In this referenced paper, a new method based on sensitivity indices derived from voltage stability improvement with respect to changes in injected active and reactive power at a bus for determining the suitable location

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for embedded generator is proposed. Evolutionary programming optimization technique has been developed in order to determine the optimal size of the embedded generation [5]. Two new approaches based on sensitivity of real and reactive power losses with respect to size and operating pint of DG has been proposed to determine the most suitable DG size and location towards minimizing power losses in the distribution systems. The proposed techniques have been developed considering the constant impedance and constant current load characteristics into account. The developed methods have been tested on a practical long radial system [6]. In [7] a new method has been suggested based on nodal pricing for optimally allocating DG in radial distribution system. An analytical expression based on real power loss sensitivity to calculate optimal DG size and optimal location of DG minimizing power losses in a distribution network was proposed in [8]. A simple and effective cumulative performance index, utilizing voltage profile improvement, loss reduction, and voltage stability index improvement is considered. Loss sensitivity factor, based on equivalent current injection method for sizing and sitting of DG in radial distribution system is given in [9]. Calculation of cost of DG is given in [10] based on conventional, triangular, and complex power limit. Authors in [11] described a technique for selection of buses in a sub transmission system for location of distributed generation (DG) and determination of their optimum capacities by minimizing transmission losses using incremental voltage (dV/dP) sensitivities. Reference [12] presented two new methodologies for optimal placement of distributed generation sources using an optimal power flow (OPF) based model in real time wholesale electricity market. The problem of optimal placement, including size, is formulated for two different objectives, namely, social welfare maximization and profit maximization. The candidate locations for DG placement are identified on the basis of locational marginal price (LMP). Optimal sizing and sitting decisions for DG capacity planning using heuristic approach was proposed in [13]. In [14] describes a Novel methodology to calculate optimal DG sizes based on real power loss. This method gives optimal DG sizes at unity power factor and it requires less computation when compared with [8].

Authors presented a methodology for optimal distributed generation (DG) allocation and sizing in distribution systems considering the losses minimization, and to guarantee acceptable reliability level and voltage profile. The GA based optimization technique has been utilized to obtain the results. The results for voltage profile and losses have been obtained based on the load flow [15]. Authors in [16] presented a method for optimal sitting and sizing of multiple distributed generators (DGs) using particle swarm optimization (PSO) based approach. A new methodology using Fuzzy and Artificial Immune System (AIS) for the placement of Distributed Generators (DGs) in a radial distribution system to reduce the real power losses and to improve the voltage profile [17]. Paper [18] deals with impact of voltage dependent load models on the predicted energy losses in DG planning. A multi-objective optimization approach considering losses reduction and voltage profile improvement for DG allocation using GA was proposed in [19]. A mixed-integer linear programming approach to determine optimal size and allocation of distributed generators (DGs) in radial distribution systems is presented in [20]. The proposed formulation accounts for the steady-state operation of the radial distribution system, considering different load levels, different types of DGs with their capability curves, the short-circuit current capacity of the circuits, and different topologies of the radial distribution system.

A multi-objective optimization approach using evolutionary algorithm with an objective of minimizing cost of energy losses, network upgrading and service interruptions for sizing and sitting of DG in distribution systems has been presented in [21]. A simple method for optimal placement of DG in radial distribution system to minimize real power loss, voltage profile improvement, substation capacity release and is based on voltage sensitivity index (VSI) analysis is presented in [22]. Ref. [23] presented an optimal proposed approach (OPA) to determine the optimal sitting and sizing of DG with multi system constraints to achieve a single or multi-objectives using genetic algorithm (GA). It deals with the benefits (voltage profile improvement, spinning reserve increasing, power flow reduction and total line loss reduction) obtained with optimal DG installation. Authors in [24] presented a simple method for investigating the problem of optimal location and capacity of DG in three-phase unbalanced radial distribution systems (URDS) for power loss minimization and to improve the voltage profile of the system using voltage index (VSI) analysis. Loss sensitivity factors (LSFs) are used to select the candidate locations for the multiple DG placements and Simulated Annealing (SA) is used to estimate the optimal size of DGs at the optimal locations in [25].

A new method for optimal sizing and sitting of DG in radial distribution systems was proposed in [26]. In this, optimal location for DG obtained by power loss sensitivity and optimal size is given by Harmony Search Algorithm (HSA). Power loss minimization in radial distribution system with network reconfiguration and distributed generation is presented in [27]. In [28] optimal placement of DG is given based on loss sensitivity and voltage stability index. A simple conventional iterative search technique along with Newton Raphson method of load flow study is implemented for DG sizing and location with an objective to lower down both cost and loss very effectively. The paper also focuses on optimization of weighting factor, which balances the cost and the loss factors [29]. The study is carried out for time invariant as well as time invariant loads incorporating single and multiple DG. A sensitivity analysis to locate DG at the respective buses and GA to obtain optimal sizes has been presented in [30]. A methodology for obtaining the optimal sizes of DG adopting two nested calculation stages taking into account time dependent generation and load is presented in [31]. A novel load flow method is proposed in [34] for RDSs which includes identifying the nodes and branches beyond any node using a sparse technique [32,33]. In [35] a new load flow method is proposed which takes into account of voltage dependent load models, and line charging capacitance. The method is based on the forward and backward voltage updating by using polynomial voltage equation for each branch and backward ladder equation (Kirchhoff's Laws). Many methods have been proposed by authors for DG location based on different approaches viz. sensitivity and optimization based. The sensitivity based methods are based on losses and voltage variation. It is essential to compare the sensitivity based methods for DG allocation and to observe the impact of DGs on cost savings and other parameters viz. losses and voltage profile.

In this work, the comparison of existing sensitivity based methods for optimal allocation of DG in radial distribution system has been presented. A method based on combined loss sensitivity and index vector methods are proposed for optimal location of DGs and comparison of the results with existing novel and voltage sensitivity index methods are presented. The Novel method was proposed for unity power factor only, however, the Novel method has been modified at lagging power factor to obtain the location and size of DGs as DGs can supply reactive power also for better voltage profile meeting real power demand also. In this paper, results have been obtained for DGs operating at unity power factor injecting only real power into the system and other operating at 0.9 power factor (lag), providing reactive power injection into the system. Optimal sizes of DG at unity and 0.9 power factor (lag) are calculated. The cost of loss savings and cost of power supplied from DGs are also calculated and comparison has been provided. The results have been obtained on 33-bus [36] and 69-bus [37] systems.