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An analytical approach for sizing and siting of DGs in balanced radial distribution networks for loss minimization

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ABSTRACT

This paper presents a novel analytical approach to determine the optimal siting and sizing of distributed generation (DG) units in balanced radial distribution network to minimize the power loss of the system. The proposed analytical expressions are based on a minimizing the loss associated with the active and reactive component of branch currents by placing the DG at various locations. This method first identifies a sequence of nodes where DG units are to be placed. The optimal sizes of DG units at the identified nodes are then evaluated by optimizing the loss saving equations and need only the results of base case load flow. To find out the best location for DG placement, a computational method is also developed. The proposed method has been tested and validated on two IEEE test distribution systems (DSs) consisting of 15 and 33-buses and it has been found that a significant loss saving can be obtained by placing DG units in the system using proposed analytical method.

Introduction

R/X ratio in distribution networks is much higher rather than transmission systems, and result of higher power losses and gradually loss of electrical energy along the distribution feeders [1–5]. Consequently, for many utilities all over the world loss minimization is one of the biggest question. Two extensive methods for loss minimization in distribution networks are network reconfiguration and capacitors placement well known and used frequently [2,3–6].

In recent past, DG has attained significant interest and can be defended, aspects such as environmental concerns, the restructuring of electricity market, the development in advance technologies for small-scale power generation, power electronics, and energy storage devices for transient backup into electric power DS [6,7]. However, this inclination has extended considerable opportunities but devised several confrontations in planning and operations of DSs. DGs are defined as electric power generations directly connected to loads or distribution networks; they range from a few kWs to a few MWs [7,8]. Today, there are many DG technologies in trend cover conventional (such as micro turbines, combustion turbine, combined cycle, and internal combustion engines) to non-conventional (such as ocean, photovoltaic solar, fuel cell, wind, and geothermal) [1,7,8].

The essential objective of DG units is energy injection; despite, strategically placed and operated DG units can offer several other benefits (i.e. technical and economical) to utilities as well as to customers [9]. Typical cases of such benefits are the application of DG units for loss reduction, voltage and loadability improvement, enhanced system reliability and security, improved power quality, increased overall energy efficiency, and relieved transmission and distribution (T&D) [6–8]. While, economical benefits cover saving world fuel, saving T&D cost and reducing whole sale electricity price. Deferred investments for upgrades of facilities, reduced operational and maintenance (O&M) costs, enhanced productivity, reduced fuel costs due to increased overall efficiency, reduced reserve requirements and the associated costs, lower operating costs due to peak shaving are the additional economical benefits [8,10,11]. As far concern to the electricity market security today's deregulation of power industry, DG units play an important role in ancillary services such as reactive power support, spinning reserve, loss compensation, frequency control and other fast response services [9,12]. Moreover, in achieving the benefits of these ancillary services; DG units have been come into view as an integral part of DS. Although, inadequately operated and poorly planned DG units may also have some adverse effect on the functioning of the DS; based on the size, location, and infiltration level they can lead to reverse power flows, voltage rise, increased fault levels, more power losses, harmonic distortion, stability problems and consecutive feeder overloads [1,9–11,13].

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It is evident that loss reduction is one of the most substantial and beneficial factor to be treated in DG planning and operation apart from factors discussed above. The major challenges in planning of DG for loss minimization are suitable location, proper sizes, and operating strategies. The DG optimal sizing and siting for minimizing losses has drawn increasing attention of the extensive group of researchers in the recent years. There have been diverse techniques/approaches employed to cover the DG siting and sizing problem in DS for power loss minimization considering different type of DG technologies with their relative advantages and disadvantages, in attaining this distinct objective along with their practicability as examined in [1,7,8,10,11]. Therefore, this paper reports the development of some simple analytical expressions for sizing and siting of DG units, which can be easily implemented in a balanced radial DS.

Remaining of the paper is set out as below: Section 'Loss minimization techniques' describe a concise literature review on earlier loss minimization methods/techniques for DG planning. In Section 'Proposed methodology', proposed analytical method for optimal size and siting for single and multiple DG is discussed. The detailed computational procedure is elaborated in Section 'Computational procedure'. Numerical results and simulation of developed analytical method applied in two IEEE test systems, interesting findings along with discussion addressed in Section 'Numerical results'. Section 'Conclusion', summarizes the major contributions and conclusions.

Loss minimization techniques

It has been realized that most of the existing work on DG siting and sizing in the DS, discussed different issues such as minimization of system power loss [1,6,10,11,13–25], abatement of harmonic pollution [19], enhancement of system voltage profile and stability [12,13,15–18,22–25], investment minimization or profit maximization [26,27], and loading margin [28] have been intended by researchers in their single or multi-objective problem formulations. Different optimization techniques, such as analytical approach [1,9–11,15,16,19,25], mixed integer non-linear programming (MINLP) [12,13,17,18], evolutionary algorithms (EA) technique [9], metaheuristic approaches: meta-heuristic harmony search algorithm (HSA) [6], particle swarm optimization (PSO) [20], heuristic approaches [27]; trade-off method [20], genetic algorithm (GA) technique [26,28], Kalman filter algorithm [23], multi-period AC optimal power flow (OPF) solver tool [20], and multi-objective non-linear programming (NLP) [15] have been used to solve the optimization problems for DG siting and sizing. Except these, there have been many interesting studies on the DGs siting and sizing of DS for loss minimization.

An analytical technique was noticed in [16] to find out the allocation of a single DG in radial as well as mesh networks to minimize the losses, based on unity power factor. However, optimal sizing is not taken into account. A more faster and precise analytical method than the classical methods [6,20,27] based on the equivalent current injection technique and without the use of impedance or Jacobian matrices for optimum size and location of DG in radial systems has been implemented in [19]. Moreover, this method was in near concurrence with the analytical method inscribed in [15]; in which an exact loss formula based analytical approach has been investigated to identify the optimal size and location of single DG in two load flow solution.

Pursuing the aforesaid work, various analytical expressions based on exact loss formula for optimal allocation of DGs were addressed in [1,10,11]. An efficient solution based on improved analytical (IA) expression to locate and size of four type of (renewable and non-renewable) DGs for loss minimization has been examined in [1]. Although multiple DGs allocation was not considered. Contrary to this, the same authors in [10] applied the same approach for multiple DG unit placement to get an utmost loss minimization in large size primary DSs. Similar kind of work was also noticed in [11] using three analytical expressions to obtain the optimum sizes and locations of renewable DGs for power loss reduction considering the combination of time-varying demand and different DG output curves.

Moreover, in [12,17,18] technique based on probabilistic planning and formulated as MINLP problem have been acquainted to the readers. In [17,18], this technique enforced to identifying the best supply, unify of various classes of non-conventional DGs (i.e. wind, biomass, and solar) to reduce the power losses yearly in DS; although, DGs competent of bringing active power only is taken into account in both the studies. Similarly, in [12] same approach was implemented on renewable DGs for best location and size so as to enhance the voltage stability margin (VSM).

In the line of above, in [23] the optimal size of DGs is determined using the Kalman filter algorithm so that total power losses are minimized. A multi-objective index-based technique to determine optimal size and location of DG units in DS with non-unity power factor considering different load models has been exposed in [24].

A multi-period AC-OPF solver based method is discussed for to determine optimal power of renewable DG sources and there size to minimize the total energy losses during a period in [20]. Authors in [22] considered an iterative DG placement technique to improve the VSM. Though losses and optimal size of DGs not considered and a fixed value is assumed for all DGs. A multi-objective method is examined in [28] for optimal placement of DGs with for loading margin and profit to be maximized considering network constraints. Although, losses and fixed reactive limits for unknown DG sizes are not studied. Recently, a new multi-objective index (IMO) based analytical expressions to accommodate a combination of photovoltaic and battery energy storage DG units for reducing energy loss and enhancing voltage stability suggested in [25] using self-correction algorithm (SCA), while considering the time-varying demand and probabilistic generation.

Most of the studies reported above, DGs considered as only pure active power source. However, it is more beneficial to improve performance of DS, when the DG units supply reactive power. Depending on the type of DG used; they can able to inject or absorbs reactive power within their capability limits [13]. Furthermore, large number of the commonly used analytical techniques for DG siting and sizing are depend on exact loss formula and expect the evaluation of the Jacobian matrix and computationally demanding more time. Therefore, the above said methods are not quite appropriate due to the intricacy, capacity and the distinct property of the DS. Consequently, the optimal allocation of either type of DG using optimal solution methodology draws added consideration.

To overcome the obstacles of earlier studies and motivated by the work of [3–5,29], this paper proposes to apply a novel and simple analytical approach which is based on the DG active and reactive branch currents and the associated loss saving for allocating the DG units for loss reduction in the radial DS. The procedure first determines the location of the DG in a consecutive way. Erstwhile the DG locations are obtained, the optimal DG capacity at each chosen locations are find out by optimizing the loss saving equation.

Proposed methodology

This segment set forth on a detailed mathematical formulation of the proposed analytical method. To develop the formulation following are the assumptions and constraints used in this paper: