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Optimal selection of distributed generating units and its placement for voltage stability enhancement and energy loss minimization

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Abstract The integration of distributed generation (DG) in distribution network may significantly affect its performance. Transmission networks are no longer accountable solely for voltage security issues in distribution networks with penetration of DGs. The reactive power support from the DG sources greatly varies with the type of DG units and may potentially distress the larger portion of the network from the voltage stability aspects. This paper presents the analysis for the selection of the best type of DG unit among different categories and its optimal location that can enhance the voltage stability of distribution network with simultaneous improvement in voltage profile. Voltage sensitivity index and bus participation factors derived from continuation power flow and Modal Analysis, respectively, are used together for voltage stability assessment and placement of DGs. Changes in mode shapes and participation factors with the placement of DGs are comprehensively analyzed for 33 and 136 nodes radial distribution network.

1. Introduction

The integration of DG is expected to play an increasingly important role in the electric power system infrastructure planning and market operations. The integration of DG at the distribution network results in operating situations that do not occur in a conventional system without generation directly connected at the distribution level [1]. Attention must be paid to effectively eliminate the potentially adverse impacts that DG penetration could impress on the electric delivery system. Inappropriate DG placement and sizing may increase system losses and network capital and operating costs. Hence, systematic studies and planning are required to locate and operate the DGs at the distribution level in order to improve voltage profile, to reduce system losses, and to enhance the stability [1–3].

Power systems are expected to become more heavily loaded in the forthcoming years as the demand for electric power rises sharply. The economic and environmental concerns limit the construction of new transmission and generation capacity. This may result in deficit of local reactive power support in

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heavily loaded system which in turn causes the progressive voltage decline [4–6]. The decline in voltage level is one of important factors which restrict the increase of load served by distribution companies. Therefore, it is necessary to consider voltage stability constraints for planning and operation of distribution systems. The shortage of reactive power can be compensated by an increased share of DGs in distribution systems to improve voltage stability. These DG sources possess different reactive power generation capability and their impact on the voltage stability should be studied distinctly. However, these types of studies are least reported in the literature.

The reactive power support using capacitor is one of the methods to reduce the power losses [7]; it is also shown that placement of many capacitors at the incorrect positions will further increase line losses. The minimization of losses does not give any assurance of the maximization of benefits unless the problem is well formulated [7–9]. However, the active power support from the capacitors cannot be possible which have significant impact on system performance. Like capacitors placement, higher penetration of the DG at the suboptimal location may increase losses in distribution lines. Hence, it is significantly essential to decide the size, location and type of DG unit to be placed. Authors in [10,11] revealed that suboptimal location for DG placement and improper sizing, would lead to higher losses as compared to the system without DG.

The issue of loss minimization in the distribution network is reported in [12] where an analytical expression and the methodology based on the exact loss formula are being used for the estimation of the optimal size and location of DG for reducing the total power losses in primary distribution systems. However, the proposed methodology is limited to DG type which is capable of delivering real power only. Multiple DG units placement using an improved analytical (IA) method to identify the best location for DG for high loss reduction in large-scale primary distribution network is given in [13]. The traditional problem of minimizing losses in distribution networks has been investigated using a single, deterministic demand level with the help of OPF in [14]. A new long term scheduling for optimal allocation and sizing of different types of DG units in the distribution networks in order to minimize power losses are presented in [15]. In [16], author discussed the iterative search method for optimal sizing and siting of single DG for minimization of cost and loss. The issue of voltage stability in distribution networks and the impact of DG units on it draw attention in recent period. A meta-heuristic technique based on backtracking search optimization algorithm (BSOA) is presented in [17] with objectives to reduce power loss and improve voltage profile in RDN considering the DG type which can inject active and reactive power both. In [18], BSOA and set of fuzzy expert roles using loss sensitivities factors and bus voltages are used to identify the DG locations. The Optimal size and location of multiple DGs are determined with particle swarm optimization using constriction factor approach in [19] considering predetermines annual load growth with voltage regulation as constraint. Simultaneous placement of DG and fixed capacitor in radial distribution network with time varying load in order to decrease reactive power loss, energy and power loss reduction, improvement of voltage profile and voltage stability has been discussed in [20].

A new voltage stability index is introduced in [21] by simplified load flow equations to seek the most sensitive buses to voltage collapse in radial networks. A method for DG placement in radial distribution network based on Voltage security margin (VSM) enhancement and loss reduction is presented in [22], which use CPF to identify the most sensitive bus to voltage collapse. The work in [23] is suggested that voltage magnitude is not a suitable indicator for the proximity to voltage collapse. Author [24] has described a technique for selection of buses in a subtransmission system for location of DG and determination of their optimum capacities by minimizing transmission losses and improvement in voltage profile.

A method is presented for locating and sizing of DGs to enhance voltage stability and to reduce network losses simultaneously in [25], where Modal analysis and continuous power flow are used for DG placement in the event of reactive power deficit. The enhancement of voltage profile, loadability with simultaneous reduction distribution losses considering voltage related constraint is discussed in [26].

Based on the literature review discussed above, it has been observed that the different issues in the field of distributed generation are covered which are based on optimal location and sizing of DG, loss minimization, voltage stability enhancement and reconfiguration of distribution network after the integration of DG resources. This paper is mainly focused on voltage stability analysis with different types of distributed generating units which were not addressed earlier in the literature. The impact of DG operating in a voltage regulation mode with varying reactive power support has been analyzed for the voltage stability enhancement. Further, the optimal location of DG is ascertained at the weakest bus which is determined by CPF and modal analysis. The variation in mode shapes with the variation in DG types and its locations have been comprehensively studied for the analysis of voltage stability. The mode shapes and participation factors are used to identify the weakest region where placement of DG may have the beneficiary effect to enhance the voltage stability. The objectives of this paper are as follows:

(1) To perform power flow analysis on a Test systems (33-nodes radial distribution network [18] and 136-nodes radial distribution [35]) without considering any DG units. These systems are considered as base case test system.
(2) To identify the weakest bus for the base case test systems by performing continuation power flow and Modal analysis.
(3) To determine and rank the buses which are more prone to voltage instability based on the mode shapes participation factors obtained through the Modal analysis.
(4) To ascertain the type of DG units and its placement methodology in a system to enhance voltage stability margin.
(5) To compare the impact of different types of DG units to improve the performance of distribution system.

2. DG technologies and their impact on voltage stability

DG technologies are classified based on their capability of injecting real and/or reactive power in the system. Accordingly, DG technologies are grouped in the following manner.