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A new approach for optimum simultaneous multi-DG distributed generation Units placement and sizing based on maximization of system loadability using HPSO (hybrid particle swarm optimization) algorithm

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ABSTRACT

This paper presents a new approach for optimum simultaneous multi-DG (distributed generation) placement and sizing based on maximization of system loadability without violating the system constraints. DG penetration level, line limit and voltage magnitudes are considered as system constraints. HPSO (hybrid particle swarm optimization) algorithm is also proposed in this paper to find the optimum solution considering maximization of system loadability and the corresponding minimum power losses. The proposed method is tested on standard 16-bus, 33-bus and 69-bus radial distribution test systems. This paper will also compare the proposed method with existing Ettehadi method and present the effectiveness of the proposed method in terms of reduction in power system losses, maximization of system loadability and voltage quality improvement.

1. Introduction

Power utilities are facing major challenges as the demand of power system is growing exponentially. The existing transmission line infra-structure is unable to support such a huge power demand. The present need is either to invest in transmission system to increase the capacity or provide the consumer demand locally by DG (distributed generation). Electric power generation integrated within the distribution systems is known as “distributed” or “dispersed” generation. The DG source can be a traditional combustion generator (such as diesel reciprocating generator and natural gas-turbine) and non-traditional generator including fuel cell, storage device and renewable energy source (such as wind turbine and photovoltaic) [1,2].

DG has many advantages over centralized power generation including power losses reduction, voltage profile improvement, system stability improvement, pollutant emission reduction, relieving transmission and distribution congestion and others [3–7]. The optimum placement of DG is necessary to achieve the maximum benefits with less investment cost [8]. After deregulation of power system, non-utility companies are investing in distribution system to meet the active power demand (MW) and get the maximum profit. For example in United States the percentage of nonutility generators in distribution system has increased from 40 GW to more than 150 GW in ten years from 1990 to 2000 [9].

In deregulated operation of distribution system, the DNO (distribution network operator) is responsible in providing good quality service to consumer and maintain the security and efficiently utilize the existing infrastructure under different uncertainties including load changes, available generation and operating schedule of DG Units, particularly in case of intermittent energy source (e.g. wind and solar). Different artificial intelligent based techniques have been proposed in literature for smooth operation of distribution system under various operational scenarios [10–15]. In some countries, the DNOs are allowed to invest DG Units based on its interests and requirements. However, in some other countries, the DNOs are not allowed to own DG Units [10].

Researchers have solved the problem of optimum DG placement problem on the basis of minimization of power losses [16–20] and voltage stability [21–27] approach. Authors have also considered DG placement as a multi-objective function, considering reduction in power losses, improved voltage regulations and voltage stability in fitness function [28]. It has also been seen in

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Ref. [29] that the DG placement also improves the reliability and voltage profile of the system. DG with reactive power control also helps in better network voltage profile and lower power losses. The DG penetration level versus power losses present a U-trajectory, thus the non-optimum placement of DG may increase the power losses [30].

The impact of DG on loadability of distribution network has also been investigated in Refs. [25,31] and concluded that the presence of DG increases the loadability of the distribution system. System loadability is related with voltages of the system, the weakest voltage buses result in poor loadability of the system. Different approaches have been proposed to increase the loadability of the system by improving the voltages of the system and the DG is placed on the selected weakest voltage bus. The weakest voltage bus is determined using eigen value determination for optimum DG location and the maximum loading margin is considered for optimum DG size in Ref. [27]. CPF (continuation power flow) method is used for weakest voltage bus determination as an optimum bus for DG placement [21]. Further authors in Ref. [21] have also extended the work for multi-DG Unit placement after first DG Unit has been placed. Authors have considered maximum loading up to the voltage constraint in fitness function for optimum DG placement using genetic algorithm in Ref. [25]. Successive modal analysis and CPF are utilized for optimum multi-DG Units placement in Ref. [22]. However techniques based on successive selection of DG position, when one DG Unit has been placed, cannot lead to the global optimum solution of maximum loadability of the system.

In this paper, a new approach for optimum simultaneous multi-DG unit placement is presented based on maximization of system loadability. System loadability (λ) is defined as the capacity of the system with which the maximum load could be connected without violating the system and operating constraints. In this paper, bus voltage and line current limit are considered as operating and system constraints respectively. In practice, it is highly needed to utilize the existing infrastructure without high investment to increase the capacity of existing system. In literature, it has been seen that the system capacity or loadability is usually limited by two factors, *thermal limits* and *voltage limits*. Thermal limit or thermal capacity is the ampacity or maximum current carrying capacity limit of the conductor. The current carrying capacity is limited by the conductor's maximum design temperature, which is determined by the insulation class use [32]. However the voltage limit is the allowable minimum–maximum voltage variation for safe operation of power system and connected load [33]. The study [33] has concluded that the maximum loadability of the distribution system is limited by the voltage limit rather than the thermal limit. The higher loading factor results in large current in the distribution line which results in high voltage drop and thus presents the poor voltage regulation. From continuation power flow (CPF) theorem [34] and results of Ref. [21], it can be concluded that increasing the maximum loadability (λ_{max}) improves the overall voltage profile, as shown in Fig. 1.

From Fig. 1, it can be observed that curve A will have overall better voltage profile than curve B at each loading. Here in Fig. 1, τ is representing the tangent (predictor vector) at different point of loading.

This paper is organized as follows: In Section 2, the need for reactive power compensation in presence of DG will be discussed. In Section 3, an optimization algorithm HPSO (hybrid particle swarm optimization) will be proposed for optimum simultaneous multi-DG Unit placement. In DG Unit placement based on maximization of system loadability, different DG location and DG size combinations may result into same maximum loadability. Thus in order to reach the optimum solution, the K-matrix in HPSO algorithm will sort the best result on the basis of minimum power losses and select the best results. In Section 4, the proposed algorithm for multi-DG Unit placement will be presented. In Section 5, the proposed algorithm will be tested on 16-bus, 33-bus and 69-bus radial distribution test systems. The present approach of optimum multi-DG Unit placement will also be compared with Ref. [22] in the same section.

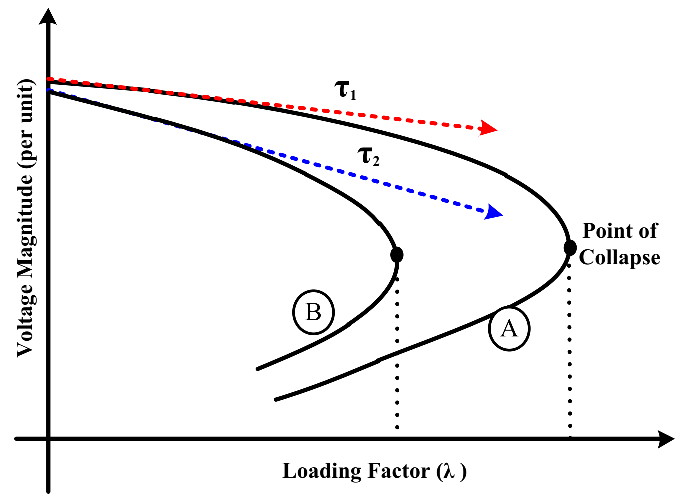

Fig. 1. Effect of maximum loadability of the system on voltage profile improvement.

2. Impact of distributed generation on voltage stability

Previously DGs were mainly considered as an active source of energy [1], however at higher system loading with maximum DG penetration, the poor voltage profile can be a big challenge for the system operator thus the reactive power compensation approach must be utilized to maintain the voltages in allowable limits [35]. DG presence in the system also affects the reactive power management plan. For example in case of wind generation, asynchronous induction generators are used. Such generators need reactive power from the system to which they are connected. Different methods of reactive compensations are stated in literature [36] including synchronous generator, shunt capacitor banks and end-user reactive power compensation within the reactive power consumption equipment. The growing trend of using non-conventional power generation (using wind and solar energy) has also led to the bounding that the renewable energy generation must play their role in improving the voltage profile and providing necessary reactive power support.

Now-a-day state of the art technology has come out to control the active and reactive power from DG. The wind generation is now using doubly fed induction generator and PV inverters are using special self-commutated line inverter, capable of absorbing and supplying reactive power at different system loading. The reactive power capability of solar and wind power plants can be further enhanced by the addition of SVC, STATCOMS and other reactive support equipment at the plant level. Currently, inverter-based reactive capability is more costly compared to the same capability supplied by synchronous machines [37–39]. The author in Ref. [40] has analysed the importance of reactive power in presence of DG and concluded that the presence of DG results into better voltage profile. However at light load in distribution system in presence of DG, the problem of voltage rise may arise, thus the voltage regulating device must also be presented in the system. The energy curtailment from DG is not a good solution as this will result in revenue lost. DG has been considered as an active source of energy in Refs. [18–20,41–43],