Electrical Power and Energy Systems 75 (2016) 226–235

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Hybrid approach for optimal placement of multiple DGs of multiple types in distribution networks

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ARTICLE INFO

Article history:
Received 14 January 2014
Accepted 11 September 2015
Available online 30 September 2015

Keywords:
Distributed generations (DGs)
Particle swarm optimization (PSO)
Optimal size
Optimal location
Power loss

ABSTRACT

In the present work, a hybrid approach has been proposed for optimal placement of multiple DGs of multiple types. The analytical approaches may not be appropriate for optimal placements of multiple DGs alone. In this work, hybridization of analytical method and heuristic search for the optimal placement of multiple DGs in power distribution network for reduction of power loss has been proposed. In this approach, the sizes of DGs are evaluated at each bus by analytical method while the locations are determined by PSO based technique. The objective function has been minimized under operating constraints. The improvements in bus voltage profile and optimal power factor of the DGs have also been observed. To validate the proposed hybrid approach, results have been compared with particle swarm optimization (PSO) technique and existing fast improved analytical (IA) method results. The proposed technique has been tested on 33-bus, and 69-bus test systems.

Introduction

The global concerns about the environment, combined with the progress of technologies to connect renewable energy sources to the grid and deregulation of electric power market have diverted the attention of distribution system planners towards grid-connected distributed generation (DG). The distributed or decentralized generation units connected to local distribution systems are not dispatchable by central operator, but they can have a significant impact on the power flow, stability, voltage profile, reliability, short circuit level and quality of power supply for customers and electricity suppliers [1]. Optimization techniques have been employed for generation allocation in power network, allowing for the best allocation of the DG. There are many approaches for deciding the optimal sizing and siting of DG units in distribution systems. Some of the factors that must be taken into account in the planning process of expanding distribution system with DG are: the number and capacity of DG units, best location and technology, the network connection, capacity of existing system, protection schemes, among others [2–5].

Including DG in distribution systems requires in-depth analysis and planning tools. This process usually includes technical, economical, regulatory, and possibly environmental challenges. Different methodologies and approaches have been developed to identify optimal places to install DG capacity on case to case basis. These methodologies are based on analytical tools, optimization programs or heuristic techniques. Most of them find the optimal allocation and size of single DG in order to reduce losses and improve voltage profiles [6,9–13]. Others include the placement of multiple DGs with artificial intelligence-based optimization methods [7,14–18] and a few go with analytical approach [11,17].

In [5], a GA based method has been proposed to find the optimal placement of DG in the compensated distribution network for restoration the system caused by cold load pick up (CLPU) condition and to conserve load diversity for reduction in line losses. In [6], PSO based algorithm has been introduced to determine the optimal size and location of a single DG unit to minimize the real power losses with the location being discrete and the size being continuous. In [7], different scenarios have been suggested for optimum distribution planning at certain locations pre-determined by the Distribution Companies aiming to improve their profiles and minimize the losses. In [8], the objective has been to minimize the real and reactive power losses of the system, improvement in the voltage profile, and the distribution line loading with different load models. In [9], an analytical method has been developed to determine the optimum location–size pair of a DG unit in order to minimize the line losses of the power system.

In [11], a GA-based algorithm has been proposed to determine the optimum size and location of multiple DG units in order to minimize the system losses and power supplied by the main grid,

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http://dx.doi.org/10.1016/j.ijepes.2015.09.002
0142-0615/

taking operational constraints into consideration. In [12], DG units have been placed at the most sensitive buses to voltage collapse. The units had the same capacity and were placed one by one. In [13,14], a GA-based algorithm has been presented to locate multiple DG units to minimize a cost function including the system losses and service interruptions. In [15], an adaptive-weight PSO algorithm has been proposed to place multiple DG units to minimize the real power loss of the system. A probabilistic-based planning technique has been proposed for determining the optimal fuel mix of different types of renewable DG units in order to minimize the annual energy losses in the distribution system [16].

Many researchers have applied artificial intelligence-based optimization techniques for finding the best locations for the placement of single or multiple DGs to reduce losses. All the mentioned research placed DG units with unity power factor. Recently, a fast analytical approach to find the optimal size of DG at optimal power factor to minimize the power loss for only type-III has been exploited [10] and another analytical multiple DG placements one by one has been presented in [17]. In fact, four types of DG are considered based on their terminal characteristics as follows:

(1) Type-I: DG capable of injecting real power only.
(2) Type-II: DG capable of injecting reactive power only.
(3) Type-III: DG capable of injecting both real and reactive power.
(4) Type-IV: DG capable of injecting real but consuming reactive power.

Most of the optimal placement techniques to allocate multiple DGs use heuristic approach only, and do not take the advantage of analytical approach. The analytical approaches may not be appropriate for optimal placements of multiple DGs alone. A hybrid approach has been proposed in the present work for optimal placement of multiple DGs of multiple types. In this work, hybridization of analytical method and heuristic search for the optimal placement of multiple DGs in power distribution network for reduction of power loss has been proposed. In this approach, the sizes of DGs are evaluated at each bus by analytical method while the locations are determined by PSO based technique. The objective function has been minimized under operating constraints. The present work develops the comprehensive formula by extending the analytical expression presented in [2,17], and a PSO based hybrid technique has been proposed to identify best locations to achieve the desired objective. In addition to the hybrid approach, PSO formulation for determining sizes and locations of DGs has been developed. Both the approaches are tested on 33-bus and 69-bus test systems and the obtained results are compared and also with obtainted results of analytical method [17].

Problem formulation

The problem of placement of multiple DGs of multiple types is to determine the optimal size and locations of multiple DGs to minimize the desired objective function as given in (1), while meeting the operational constraints.

Objective function

The objective is to minimize the total real power loss as given in (1) while meeting the following constraints. This formula is popularly referred as “Exact Loss” formula [18].

$$Min\ P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)\right] \tag{1}$$

Constraints

- For each bus, the following power flow equations must be satisfied.

$$P_{Gi} - P_{Di} = \sum_{j=1}^{N} V_iV_j\left[G_{ij}\cos\left(\delta_i - \delta_j\right) + B_{ij}\sin\left(\delta_i - \delta_j\right)\right] \quad \forall i = 1,2,3,\ldots,N \tag{2}$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N} V_iV_j\left[G_{ij}\sin\left(\delta_i - \delta_j\right) - B_{ij}\cos\left(\delta_i - \delta_j\right)\right] \quad \forall i = 1,2,3,\ldots,N \tag{3}$$

- The sizing and locations are considered at peak load only.
- The voltage at every bus in the network should be within the acceptable range. American National Standards Institute (C84.1-1989) has stipulated that voltage variations in a distribution system should be controlled within the range of −13% to 7% [19]. In this work, the voltage variations are set at 0.90 pu and 1.05 pu, respectively.

$$V_{min} \leqslant V_i \leqslant V_{max} \quad \forall_i \in \{buses\ of\ the\ network\} \tag{4}$$

- Current in a feeder or conductor, must be well within the maximum thermal capacity of the conductor

$$I_i \leqslant I_i^{Rated} \quad \forall_i \in \{branches\ of\ the\ network\} \tag{5}$$

Here, I_i^{Rated} is current permissible for branch i within safe limit of temperature.

Proposed approaches

The problem formulated above for the placement of multiple DGs of multiple types have been solved by the following two approaches, proposed in this work.

(i) Hybrid approach
(ii) PSO based approach

Hybrid approach

In this approach, an analytical method has been improvised as described in [17] for placement of multiple numbers of DGs of multiple types. In this method a mathematical approach is given to find the sizes of DGs but optimal locations are found using PSO based technique. This method can be implemented to find any combination of different types of DGs is described below.

Sizing of multiple DGs

The total power losses will be formulated as based on real power loss in the system is given by (1) and is reproduced below.

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)\right]$$

where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right)$$

and

$Z_{ij} = r_{ij} + jx_{ij}$ are the ijth elements of $[Z\ bus]$ matrix,

$P_i = P_{Gi} - P_{Di}$ and $Q_i = Q_{Gi} - Q_{Di}$