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A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks

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ABSTRACT

This paper presents a novel integration technique for optimal network reconfiguration and distributed generation (DG) placement in distribution system with an objective of power loss minimization and voltage stability enhancement. Fireworks Algorithm (FWA) is used to simultaneously reconfigure and allocate optimal DG units in a distribution network. FWA is a new swarm intelligence based optimization algorithm which is conceptualized using the fireworks explosion process of searching for a best location of sparks. The radial nature of the network is secured by generating proper parent node-child node path of the network during power flow. Voltage Stability Index (VSI) is used to pre-identify the optimal candidate locations for DG installation. Six different scenarios are considered during DG placement and reconfiguration of network to assess the performance of the proposed technique. Simulations are carried out on well-known IEEE 33- and 69-bus test systems at three different load levels. The simulated results demonstrate well the performance and effectiveness of the proposed method.

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Introduction

In recent times, electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. Studies indicate that almost 10–13% of the total power generated is lost as I^2R losses at the distribution level [1], which in turn, causes increase in the cost of energy and poor voltage profile along the distribution feeder. Therefore, it becomes important to improve the reliability of the power transmission in distribution networks. The most common methods used for voltage stability enhancement and power loss reduction in power distribution systems are network reconfiguration and DG placement [2]. The configuration of the network, placement and size of DG units should be optimal to maximize the benefits and reduce their impact on the power system. Thus the optimal integration between these two problems becomes a significant and complex problem.

Network reconfiguration is the process of changing the topology by altering the open/closed status of switches, so as to find a radial operating structure that minimizes the losses and improves the voltage stability while satisfying the operating constraints. Many researchers solved the network reconfiguration problems using different methods for the last two decades [2]. Authors in [3] were the first to solve the network reconfiguration problem for loss minimization using a branch and bound-type optimization technique. Later on, several optimization algorithms have been developed for loss minimization and/or voltage profile improvement. Authors in [4] used a discrete artificial bee colony algorithm to find the maximum loadability point by optimizing the distribution network, and also used continuation power flow along with graph theory to compute power flow. In [5], authors solved the reconfiguration problem assuming a series fault at a bus using Bacterial Foraging Optimization Algorithm (BFOA). Authors in [6] proposed modified honey bee mating optimization algorithm to investigate the network reconfiguration problem with the consideration effect of the renewable energy sources. In the very latest researches, a new non-revisiting genetic algorithm had been proposed for solving the reconfiguration problem [7].

DG units are small generating plants connected directly to the distribution network or on the customer site of the meter. The number of DG units installed in the distribution system has been increasing significantly, and their technical, economical, and environmental impacts on power system are being analyzed. The most critical factors that influence the technical and economic impacts are type, size, and location of DG units in power system. Recently, several studies have been carried out on impact of DG units [8–12]. Authors in [8,9] presented an analytical and improved analytical expression for finding the optimal location and size of DG units

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Nomenclature

P_{Lk}	real power load at bus k
P_k	real power flowing out of bus k
$P_{k+1,eff}$	total effective real power load fed through the bus $k + 1$
I_k	equivalent current injected at node k
J_k	branch current in the line section between buses k and $k + 1$
R_k	resistance of the line section between buses k and $k + 1$
$P_{\text{Loss}}(k, k+1)$	real power loss in the line connecting buses k and $k + 1$
$P^R_{T,\text{Loss}}$	total power loss of the system after reconfiguration
$P^{\min}_{\text{TDG}}$	minimum total real power generation limit
$P_{DG,k}$	real power supplied by DG at node k
P_{TDG}	total real power supplied by DG in the system
S_k	apparent power flowing in the line section between buses k and $k + 1$
V_{worst}	Worst voltage magnitude of the system.
n	total number of buses
Q_{Lk}	reactive power load at bus k
Q_k	reactive power flowing out of bus k
$Q_{k+1,eff}$	total effective reactive power load fed through the bus $k + 1$
V_k	voltage magnitude at bus k
$\Delta V_{\max}$	maximum voltage drop limit between buses 1 (substation) and k
X_k	reactance of the line section between buses k and $k + 1$
$P_{T,\text{Loss}}$	total power loss of the system (base case)
$P^{DG}_{T,\text{Loss}}$	total power loss of the system with DGs
$P^{\max}_{\text{TDG}}$	maximum total real power generation limit
P_{SS}	power supplied by the substation
nd	number of candidate buses for DG installation
$S_{k,\max}$	maximum power flow capacity limit of line section between buses k and $k + 1$
nb	total number of branches

for reducing power loss along with methodologies for identifying the optimal location. Authors in [10] proposed Particle Swarm Optimization (PSO) based technique to solve the optimal placement of different types of DGs for power loss minimization. In [11], authors proposed a new method which employs a modified teaching–learning based optimization algorithm to determine the optimal site and size of DG units. In [12], authors introduced a hybrid population-based algorithm with the combination of PSO and gravitational search algorithm to determine the optimal place and size of multi-DG units in distribution systems. More recently, BFOA based approach had been proposed to solve the DG placement problem at different load levels [13].

All the above researches [2–13] focussed only on the optimization of either distribution network or the DG placement. However, the objective was to minimize the power loss and/or to improve the voltage stability, network reconfiguration usually did not take the DG units into consideration and vice versa. To benefit the whole distribution network effectively, it is necessary to integrate both the network reconfiguration and DG placement problems [14,15]. In [16], authors have dealt network reconfiguration and DG placement simultaneously using Harmony Search Algorithm (HSA) based only on minimization of power losses.

The novelty of this paper is that it proposes recently developed fireworks optimization algorithm for solving the distribution system network reconfiguration together with DG placement for the problem of power loss minimization and voltage stability enhancement. The proposed technique makes use of VSI to pre-identify the candidate bus locations for DG installation. Also the technique monitors the radial nature of the network at all phases of reconfiguration by generating proper parent node-child node path during power flow. The proposed technique has been validated on two standard IEEE 33- and 69-bus test systems, and the results simulated are compared with the results of other classical techniques available in the literature to assess the performance and effectiveness of the proposed method.

Problem formulation

Radial nature of the system

To monitor the radial nature of the distribution network, the nodes of the distribution system are optimally ordered in order to generate proper parent node child node path as in [17]. This path generation will ensure the radial nature of the system, also prevents the creation of unconnected branches or nodes, and formation of mesh loops. Hence at each phase of distribution system reconfiguration, the power flow is carried out only after the generation of proper parent node child node path. For the sample system shown in Fig. 1, the generation of parent node child node path is illustrated in Table 1.

Power flow equations

Distribution system power flow is calculated by the following set of recursive equations derived from the single line diagram shown in Fig. 2.

From Fig. 2, the equivalent current injected at node k is calculated as

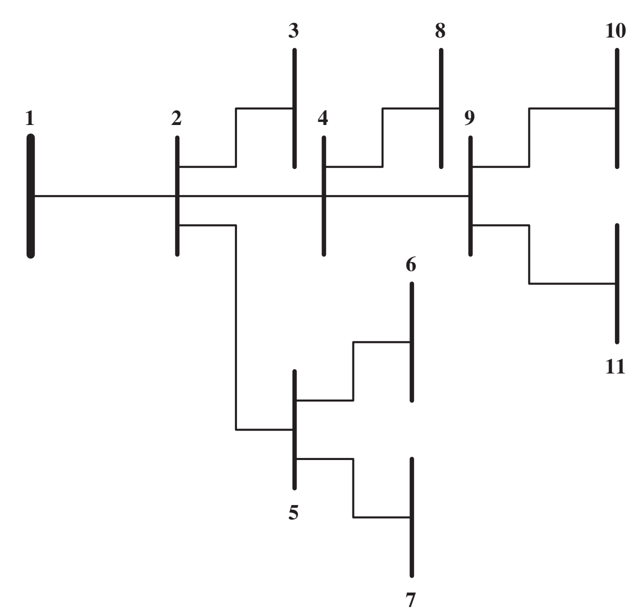

Fig. 1. Sample distribution system.

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