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A new power system reconfiguration scheme for power loss minimization and voltage profile enhancement using Fireworks Algorithm

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A R T I C L E I N F O

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A B S T R A C T

In this paper, a new efficient method to solve the network reconfiguration with an objective of improving power loss minimization and voltage profile of the distribution system is presented. A new Meta-heuristics Fireworks Algorithm (FWA) is proposed to optimize the radial distribution network while satisfying the operating constraints. FWA is a recently developed swarm intelligence based optimization algorithm which is conceptualized using the fireworks explosion process of searching for a best location of sparks. Network reconfiguration is formulated as a complex combinatorial optimization problem. The radial nature of the system is secured by generating proper parent node–child node path of the network during power flow. To demonstrate the applicability of the proposed method, it is tested on a standard IEEE 33- and 119-bus system. The simulated results are compared with other methods available in the literature. It is observed that the performance of proposed method is better than the other methods in terms of quality of solutions. Different abnormal cases are also considered during reconfiguration of network to study the effectiveness of the proposed method and the results obtained are found to be encouraging.

Introduction

To satisfy the customer demands in a reliable and more economical manner is the main objective of a modern electric power system. The distribution system delivers power to a variety of loads, i.e. residential, industrial, commercial, etc., which are typically subjected to daily load variations over a wide range. With the increased loading and exploitation of the existing power structure, the probability of occurrence of voltage collapse is significantly increasing in the distribution system. Distribution system 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 loss and improves the voltage stability while satisfying the operating constraints. Under normal conditions, the DISCOs may expect to reduce the system power losses and balance the loading among transformers and feeders. On the other hand, the need of improving power quality has become progressively essential. More specifically, sensitive loads can only be subjected to less voltage drop and shorter interruption while abnormal conditions (faults) occur [1]. Even under faulted conditions, DISCOs or supply companies should ensure the quality of power supplied to the industries with the sensitive loads. Therefore, the feeder configuration problem becomes more complicated with the conflicting objectives of satisfying both normal and abnormal conditions.

In last two decades, many researchers had solved the network reconfiguration problem using different methods with the objective of power loss minimization and/or voltage profile improvement in power distribution networks. Authors in [2] were the first to solve the distribution system reconfiguration problem for loss reduction using a branch and bound-type optimization technique. The main disadvantage of this method was computation time taken for obtaining optimal configuration. Authors in [3] had solved the reconfiguration problem using two minimum-current neighbor-chain updating methods. Authors in [4] presented a new method for distribution network reconfiguration integrated with optimal power flow based on a benders decomposition approach for loss minimization and load balancing. Authors in [5] had implemented differential evolution algorithm to enhance power quality issues such as harmonics and voltage sags by optimizing the distribution network.

Later on, numerous optimization algorithms like fuzzy adaptation evolutionary programming [6], fuzzy mutated genetic algorithm [7], Refined Genetic Algorithm (RGA) [8], binary particle

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Nomenclature

P_{Lk}	real power load at bus k
P_k	real power flowing out of bus k
I_k	equivalent current injected at node k
V_k	voltage magnitude at bus k
R_k	resistance of the line section between buses k and $k+1$
$P_{Loss}(k, k+1)$	real power loss in the line connecting buses k and $k+1$
$P_{T,Loss}$	total power loss of the system (base case)
S_k	apparent power flowing in the line section between buses k and $k+1$
n_t	total number of buses in radial distribution system
Q_{Lk}	reactive power load at bus k
Q_k	reactive power flowing out of bus k
J_k	branch current in the line section between buses k and $k+1$
$\Delta V_{\max}$	maximum voltage deviation limit between buses 1(substation) and k
X_k	reactance of the line section between buses k and $k+1$
V_{worst}	worst voltage magnitude of the system
$P^R_{T,Loss}$	total power loss of the system after reconfiguration (optimum case)
$S_{k,\max}$	maximum power flow capacity limit of line section between buses k and $k+1$
n_b	total number of branches in radial distribution system

swarm optimization [9], plant growth simulation algorithm [10] and Harmonic Search Algorithm (HSA) [11,12] had been proposed to solve the reconfiguration problem with various objectives. In the very recent researches, discrete artificial bee colony [13] and particle swarm optimization [14] along with graph theory had been proposed to optimize the distribution network.

All the above researches [1–14] mentioned have gained encouraging results in solving the problem of distribution network optimization, but they also have some shortcoming in some respects such as computation time in solving large scale systems, inclusion of external parameters like crossover rate and mutation rate, convergence property and computing efficiency. Also the above researches are implemented only under normal condition (operation) of distributed systems.

Authors in [15] had optimized the radial distribution network assuming a series fault at a bus using Bacterial Foraging Optimization Algorithm (BFOA). But the optimal configuration obtained was not found to be in radial nature, and it is observed that it forms a mesh loop in the network. This would collapse and endanger the entire radial distribution network. Hence maintaining radial nature of distribution system becomes vital at all phases of reconfiguration.

In the present work, a new Fireworks Algorithm (FWA) is proposed for optimizing the radial distribution network. FWA is robust, stochastic and is one of the most efficient evolutionary algorithms. The main objective of this paper is to minimize the power loss and voltage deviation, and also to maintain the radial nature of the distribution system. The novelty of this article lies in the implementation of new swarm intelligence based global optimization process FWA, for solving the complex combinatorial reconfiguration problem. Also the novelty lies in implementing the proposed method under abnormal conditions. Under abnormal conditions, the proposed method will isolate the faulted areas and assures power supply to the non-faulted areas of the system with minimum voltage deviation and load shedding. The proposed method is tested on two standard IEEE test systems and the results obtained are very encouraging. Further, the simulated results are compared with other methods available in the literature to evaluate the performance of the proposed method.

Problem formulation

Radial nature of the distribution network

For reconfiguration problem, the radial nature of the network is considered as a very important constraint. To maintain the radial nature of the distribution network during reconfiguration, the nodes of the distribution system are optimally ordered in order to generate proper parent node–child node path as in [16]. 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 of the network. For the sample distribution network 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 basic recursive equations [17] derived from the single line diagram shown in Fig. 2.

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

$$I_k = \left(\frac{P_{Lk} + jQ_{Lk}}{V_k}\right)^* \tag{1}$$

Branch current in the line section k is calculated by using Kirchhoff's Current law as

$$J_k = I_{k+1} + I_{k+2} \tag{2}$$

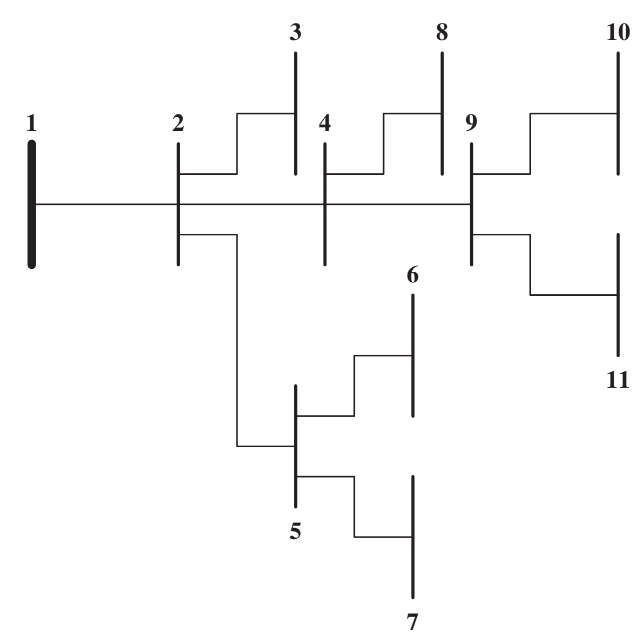

Fig. 1. Sample distribution system.