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# Reconfiguration of distribution networks with optimal placement of distributed generations in the presence of remote voltage controlled bus

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ABSTRACT

This paper presents the reconfiguration of the distribution network in the presence of distributed generations (DGs) by considering two bus types i.e., P bus and PQV bus (remotely voltage controlled bus). The 'P' bus is represented by active power specification only whereas the PQV bus is one whose voltage is remotely controlled by the P bus. A methodology is proposed to select the P bus for controlling the voltage magnitude of remotely located PQV bus. A sensitivity analysis approach is used for selecting the buses for the placement of DGs operating at unity power factor. The placement of DGs is done in two ways i.e., non-sequential placement and sequential placement of DG in a distribution network. Genetic algorithm (GA) technique is used for the optimization of DGs followed by network reconfiguration. The objective function for network reconfiguration in this paper is considered to be real power loss reduction. Effectiveness of the proposed method is demonstrated through examples of 33 bus and 69 bus distribution networks.

## 1. Introduction

The configuration of a distribution network can be changed by opening/closing the tie switches of the network. The advantages of this technique are reduction in real power loss and enhanced system reliability as well as power quality. The radiality of the network is to be maintained while performing this technique in order to comply with the protective relaying requirements. The problem of achieving real power loss reduction by changing the network structure (maintaining the radiality at the same time) has received considerable research interest in this context.

Merlin and Back [1] first came up with the idea of network power loss reduction with distribution network reconfiguration using a branch and bound optimization technique. Civanlar et al. [2] made use of branch exchange heuristics operation for switching in order to reduce the line losses in the network. A heuristic method based on the idea presented by [1] has been described by Shirmohammadi and Hong [3] to overcome the drawbacks in [1]. In [3], the tie-switches are all initially closed to form a meshed network. The tie-switches are opened one at a time by satisfying the desired objectives using the heuristics method in [3] to retain the radial structure. Baran and Wu [4] have followed the solution approach proposed by Civanlar et al. [2] by introducing two different methods to approximate the power flow in the system. The network reconfiguration in [4] is carried out for loss reduction as well as for load balancing. Chiang and Jumeau [5] have proposed a two stage modified simulated annealing technique to optimize a constraint multiobjective, non-differential optimization problem. A minimization mixed integer programming problem to minimize the losses in a network has been proposed by Kara et al. [6]. The objective function in [6] is solved using genetic algorithm tool which is shown to be computationally faster than the previous mentioned methods. A heuristic algorithm based on optimum flow pattern by solving the KVL and KCL has been reported by Goswami and Basu [7]. Unlike in all other methods where all the tie-switches are closed to form a meshed network at first, in [7] one switch is closed at an instant to form a loop and upon satisfying the optimal power flow pattern, one switch is opened to retain the radial structure. Peponis and Papadopoulos [8] have presented two heuristic reconfiguration strategies for loss reduction or load balancing. This network strategy has been exercised on a large scale network using switch exchange operations. Abur [9] has formulated the reconfiguration problem as a minimum cost network flow problem using linear programming by considering the line capacity limits. Zhu [10] has proposed an improved method to minimize the distribution network power loss using a refined GA to avoid premature convergence. In [10], the author has further modified the genetic algorithm tool to obtain better performance than [6]. Prasad et al. [11] have formulated a fuzzy mutated GA for optimal reconfiguration of the radial distribution systems. The method proposed in [11] can deal with non-continuous multi-objective optimization problem with an effective solution search

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space using a modified chromosome representation and a fuzzy mutation control. Su et al. [12] have presented ant colony search algorithm for optimal network reconfiguration. The numerical results presented in [12] show that the ant colony search method is better than genetic algorithm and simulated annealing optimization technique when applied on a 3 feeder, 16 node sample distribution network and 11 feeder, 83 node practical distribution network of Taiwan Power Company. Schmidt et al. [13] have formulated a mixed integer nonlinear optimization problem where the integer and continuous variables represents the state of the switches and the current flowing through the branches respectively. Gomes et al. [14] have analyzed the distribution system reconfiguration based on optimum power flow. The opening and closing of branches are represented by continuous functions based on the sensitivity given by optimal power flow. Artificial neural network (ANN) technique has been proposed by Salazar et al. [15] to minimize the power losses in the network and the use of clustering techniques is proposed to improve the performance and structure of the ANN. A GA addressed population generation criteria avoiding non-feasible individuals from a network structure has been proposed and evaluated by Mendoza et al. [16] for minimal loss network reconfiguration. Carrens et al. [17] have proposed a technique that generates radial topologies after the implementation of genetic operators in a specialized GA to find efficient solutions. Raju and Bijwe [18] have described a two stage, heuristic method for determining a minimum loss configuration of a network based on real power sensitivities. A variation based approach to ant colony optimization (ACO) i.e., hyper-cube ACO has been introduced by Carpaneto et al. [19] for minimum loss reconfiguration. Cebrian and Kagan [20] have used a computational implementation of an evolutionary algorithm to minimize losses. Ababei et al. [21] have proposed a minimum cost maximum flow based reconfiguration algorithm along with a random walk based loss estimation technique for network reconfiguration to reduce the computation time and losses. Zin et al. [22] have proposed a heuristic method based on minimum branch current technique where tie-switches can be updated repeatedly by a circular updating mechanism. Taylor and Hova [23] have derived three convex models representing formulations of the ac problem that have convex, continuous relaxations. Jabr et al. [24] have proposed a mixed integer conic programming formulation for the minimum loss distribution network reconfiguration problem employing a convex representation of the network model which optimizes the exact value of the network losses. Gonzalez et al. [25] have presented a method for computing the sensitivities of the state variables of the network with respect to switching operations in radial networks for accurate estimates and low computation load. Subsequently, Zin et al. [26] have also proposed another two stage heuristic method for obtaining the global optimum solution using the minimum current updating and neighbor chain updating technique. Wang and Gao [27] have introduced a non-revisiting GA (NrGA) to determine network reconfiguration for loss reduction. Inoue et al. [28] have developed a compressed search space using a binary decision diagram to minimize the optimization problem to a shortest path finding problem for determining minimum loss configuration in a distribution network.

Gradually, research work focused on optimal placement and sizing of DGs in the distribution networks has drawn interests since the last decade. Optimal placement and sizing of DGs has been carried out using discrete PSO, GA and optimal power flow [30–32]. Garcia and Mena [29] have considered an evolutionary method called Teaching-Learning based Optimization (TLBO) algorithm with modifications to solve the optimal DG placement and sizing problem. Multi-objective optimization models have also been formulated in several literature [33–36]. Moravej and Akhlaghi [37] have proposed a methodology based on cuckoo search algorithm for optimal placement and sizing of DG in the distribution network. Heuristics and analytical approaches have also been carried out for placement and sizing of DGs [38–41]. Liu et al. [42] have presented the optimal placement and sizing of the DGs considering the time sequence characteristics of loads and DGs. Viral and Khatod [43] have presented a review paper based on optimal planning of distributed generation systems. Murthy and Kumar [44] have presented a comparison of various DG allocation methods for optimal placement in radial distribution network.

Research focused on network reconfiguration in the presence of distributed generations has started gaining momentum in the present decade. The incorporation of network reconfiguration in the presence of DGs leads to overall technical benefits in the distribution network. Wu et al. [45] have aimed at achieving the minimum power loss and increment load balance factor of distribution network with DGs by proposing a methodology based on ant colony algorithm. Guan et al. [47] have presented the network reconfiguration considering different DG sources using modified quantum particle swarm optimization technique. Network reconfiguration in the presence of DGs has also been carried out using discrete teaching-learning based optimization algorithm and mixed integer linear programming models [48,49]. Heuristic algorithms have been considered for the formulation of network reconfiguration problem in the presence of distributed generations [49–52]. Nayak [53] has solved the loss minimization network reconfiguration problem using Hyper Ant Colony optimization algorithm in the presence of distributed generations. Rao et al. [54] have presented a meta-heuristics harmony search algorithm for loss minimization using different scenarios of DG placement and network reconfiguration. A heuristic algorithm based on sensitivity indices has been proposed by Rossetti et al. [55] for optimal placement of DG with network reconfiguration. Rajaram et al. [56] have formulated a modified plant growth simulation algorithm for network reconfiguration in the presence of DGs for loss minimization. The algorithm presented in [56] is seen to be more efficient than the methods proposed in [53–55].

In recent years, a new concept of P and PQV buses (requiring remote voltage control) has come up. PV and PQ are the conventional bus types. Remote voltage control requires the PQV bus to be controlled by a generation bus (P bus) [57–59]. The known quantities in the PQV bus are real power, reactive power and voltage magnitude. The placement of DG in the presence of P & PQV bus has been reported in [60]. Tah and Das [60] have presented DG placement with and without the presence of P and PQV buses using analytical method. The network reconfiguration is however not considered in [60]. The main aspects of the reviewed literature have been summarized in the form of a table and are presented in Table 1.

From the above table, it could be seen that the network reconfiguration considering P and PQV buses in the presence of distributed generations has not been reported so far in the literature. Hence, the aforesaid objective has been tried and incorporated in this paper. The effectiveness of the proposed objective has been demonstrated using 33 and 69 node distribution networks. This paper proposes the placement and sizing of DGs in two ways (non-sequential & sequential approach) along with reconfiguration of the network. This combinatorial approach is adopted to reduce the real and reactive power losses, improve the voltage profile, enhance the system reliability and security, and improve the overall technical benefits. A simple methodology is adopted based on loss reduction for selecting P type bus and reactive power injection at P type bus is computed after the load flow study. The appropriate size of the shunt capacitor to be connected at P type bus to control the voltage magnitude of PQV bus is also computed.

The main contributions of this paper are:

- Incorporation of P and PQV buses into the distribution network and to suggest a methodology for selecting P bus to control the voltage magnitude of a remotely located PQV bus.
- Reconfiguration of the distribution network for power loss minimization (based on voltage difference heuristics using modified circular mechanism) with and without considering DGs operating at unity power factor in the presence of P and PQV buses.