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Optimal reconfiguration of radial MV networks with load profiles in the presence of renewable energy based decentralized generation

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ABSTRACT

The main concern of integration the renewable energy into the supply grid, in Germany, is to reach about 35% of the total generation by 2030. In this case, a large amount of the produced power will be provided as Decentralized Generation (DG). Therefore, the future distribution networks with the high penetration of DG power have to be planned and operated in order to improve their efficiency. Thus, the current study proposes a new methodology for reconfiguration of radial MV networks with the existence of renewable energy based DG units. Since the main concept of the proposed methodology is to minimize the energy loss, definition of a typical network, based on a real life urban network, will be handled. In this regards, the optimization algorithm was formulated using a combination of Tabu Search (TS) and Branch Exchange (BE). The utilized algorithm was based on C++ and NEPLAN – power system analysis software. Whereas, the load profiles of residential and commercial loads were used through the implementation of the algorithm. Two phases were conducted in the implementation of the proposed algorithm. In the first phase, the DG power has been assumed to be constant at different percentages of the rated power of each unit. In the second phase, the DG with generation profiles has been considered. At that end, the current methodology demonstrated a high performance in minimizing the energy loss, improving the voltage profiles and relieving the bottlenecks in the lines.

1. Introduction

Recently, the interest in Distribution Automation (DA) leading to Smart Grids has been widely grown as an important issue. The network reconfiguration process, which is one of the DA functions, improves the load flow of the distribution networks by changing the status of the switches without violating the operating constraints. Therefore, the reconfiguration is exploited for loss reduction, relief of overloads (load balancing), Volt/Var support (maximizing loadability), and system restoration [1]. The reconfiguration algorithms can be identified by the solution methods that employ: algorithms based upon a blend of heuristics and optimization methods, algorithms based solely on heuristics, and Artificial Intelligence (AI) based techniques [2]. Based on the reported studies, the introduction of DG in power distribution networks will increase the complexity of the reconfiguration problem. Reconfiguration of distribution networks can be conducted considering the load profile, generation profile, hybrid (i.e. load and generation profiles), constant load, or constant generation. In the previous studies, the optimal reconfiguration of distribution networks was illustrated to include system operation, planning, and DG placement. Briefly, the influence of DG on the distribution networks using a time variant load and a constant output power of DG was investigated by Agustoni et al. [3]. While, the distribution networks graphic simulator, developed with reconfiguration functions and a special focus on loss allocation, both considering the presence of DG was discussed by Oliveria et al. [4]. The Genetic Algorithm (GA) for reconfiguration of a distribution network with the existence of DG units, which was considered as a constant supplying power at a

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certain power factor, was used by Choi et al. [5]. Calderaro et al. [6] implemented the reconfiguration of distribution networks for maximizing the capacity of DG which can be interconnected while the operating constraints were kept within their limits. The TS was used by Rugthaicharoencheep et al. [7,8] for optimal reconfiguration of distribution systems with the existence of DG units to minimize the power loss. Mishima [9] exploited the TS for reconfiguration of distribution networks. The authors have developed their methods dealing with equally distributed loads. The algorithm was implemented in different cases, such as the system without DG, only one DG is existed, and multiple DGs were connected. Consequently, with a different output power of wind energy, Zhang et al. [10] showed a method to get the optimal network reconfiguration scheme of distribution networks. Kargar and Maleki [11] introduced a reconfiguration method of distribution networks with DG based on Imperialist Competitive Algorithm (ICA) with objectives of minimizing the loss and increment the load balance. Syahputra et al. [12] developed a reconfiguration methodology based on a fuzzy multi-objective approach. A methodology for distribution networks reconfiguration based on Simulated Annealing (SA) using Open Distribution Simulator Software (Open DSS) was modified by Nie et al. [13]. Random characteristics of wind power generation were considered for the distribution network reconfiguration [14]. The optimization was performed based on multiple objective Particle Swarm (PS) algorithm. In this regards, the wind power was utilized based on two scenarios; a single and multiple wind farm scenarios. The optimum operation of a distribution network in the presence of DG and capacitors using system reconfiguration was demonstrated [15]. Based on Ant Colony (AC) algorithm, a reconfiguration methodology was established [16]. Therefore, in the current study, a new switching state optimization method for radial MV distribution network is proposed. The main concern of our study was based on the BE and TS for minimizing the energy loss of distribution networks in the presence of renewable energy based DG units. In terms of that purpose, minimizing the energy loss, a nonlinear optimization problem was formulated. Thus, the current method enables an easy way to identify the time horizon for conducting the optimization process. As a result, selection of 1 h, one day, one week, month, or a year will be possible. Moreover, the proposed method offers the use of load and generation profiles. At that end, the profiles can be measured, standardized, or forecasted. Forecasting approaches of the renewable energy based resources generation profiles such as wind and PV will be evolved into the new concept of the Smart Grid [17,18]. These approaches will provide the proposed methodology with generation and load profiles to be exploited in the switching optimization process. Hence, the optimum switching state of a day ahead can be identified. The structure of the current study will be presented in several sections. Introduction to the TS will be shown in the next section. While in Sections 3 and 4 the problem formulation and the solution mechanism will be illustrated, respectively. Sections 5 and 6 represents the typical distribution network and the implementation phases of the proposed approach. The results will be carefully explained in Section 7. Finally, the conclusions will be summarized in Section 8.

2. Tabu Search

"Tabu Search (TS) is basically a gradient-descent search with memory. The memory preserves a number of previously visited states along with a number of states that might be considered undesired. This information is stored in a tabu list" [19]. The most important parameters in the TS are the definition of the state, the area around the state, and finally the length of the tabu list [19]. Moreover, there are two extra parameters which are often used, aspiration and diversification. "Aspiration is used when all the neighboring states of the current state are also included in the tabu list. In that case, the tabu obstacle is overridden by selecting a new state while; diversification adds randomness to this otherwise deterministic search. If the Tabu Search is not converging, the search is reset randomly" [19]. Using the TS, the optimum solution is approached by searching the solution of the neighbor state. In the tabu list every exchange step is stored; it called a "tabu" and cannot be turned around again. Through the tabu list the local and global solution space can be covered and this is one of the advantages of the TS method. The computational cost in the TS methods is lower than that of the GA method [9]. Therefore, the TS can achieve the optimal or suboptimal solution within a reasonably short time. In terms of initial conditions the TS is straightforward and deterministic so that it is more robust than GA. In the TS method the search for the optimal solution is performed in a more aggressive way compared to the case of SA and GA. Based on these advantages, the TS method since 1999, is used in different optimization applications in power system [20]. One of these applications is the reconfiguration of distribution networks with distributed power generation [9]. In the current work the TS has been selected because it depends on an initial solution, and this is valid for the networks under study, while both GA and TS are applied to the reconfiguration optimization of distribution networks with the existence of DG units [5,9].

3. Problem formulation

In the reported studies two types of switches in the distribution networks are always implemented in the reconfiguration process: tie switches and sectionalizing switches. Tie switches are the switches which are used to connect different branches or feeders, while the sectionalizing switches are utilized to switch between the MV substations through the feeder. In the current study the switches at the two ends of the branches are only used in the reconfiguration process as has been identified by the network operator because only these switches can be automatically switched. Therefore, each branch is summarized between these two switches through the optimization process. The main concern of the proposed reconfiguration methodology is the minimizing of the energy loss with turning the switches on/off. To that end, the reconfiguration problem has the following constrains:

1. Power flow equations.
2. Voltage magnitudes at each node in the system must be within the acceptable limits, which are provided by the network operator (±3%).
3. Line currents in all branches has to be within their acceptable limits.
4. The radial structure of the system must be maintained.
5. No interconnection between the HV stations.
6. All nodes have to be energized.

Mathematically, the problem can be formulated as follows:

$$\text{Min}Z = \sum_{m=1}^{m=24} \sum_{k \in B} |I_k^m|^2 R_k \quad (1)$$

Subject to

$$g(x) = 0 \quad (2)$$

$$V_i^{\min} < V_i < V_i^{\max} \quad (3)$$

$$I_k^{\min} < I_k < I_k^{\max} \quad (4)$$

where Z is the objective function (Wh), I_k^m is the branch k current during m hour obtained by running the load flow, therefore the number of points per day is 24. R_k is the branch resistance, B is the