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Multi-objective dynamic distribution feeder reconfiguration in automated distribution systems

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A B S T R A C T

Distribution feeder reconfiguration is an important operation problem in distribution system which has been used to improve the efficiency of distribution systems by obtaining the best combination of on/off status of the switches. It is a mixed integer non-linear program problem and hence hard to solve which necessitate employing proper optimization algorithms to converge to global optima or find near global optima. Smart grid implementation has made loads and electricity prices more volatile and as a result makes operational power system problems to be much more time dependent and more complicated rather than before. To cope with these time dependencies, it is crucial to extend the problems on different time intervals. To this end the dynamic distribution feeder reconfiguration, extension of the problem over multiple time intervals, with various objective functions including operation cost, power loss and energy not supplied is developed and investigated in this study. Time varying electricity prices and different load levels juxtapose with the effect of distributed generations are taken into account in order to generalize the proposed approach. Inherent complexities of distribution feeder reconfiguration problem have made proposing solution techniques an ongoing research topic. A new optimization algorithm is proposed to solve the proposed problem.

1. Introduction

Distribution systems consist of buses, lines, and (sectionalizing and tie) switches that can be opened or closed. They have mesh structure. However, they usually operate in radial configuration because many operation and control in distribution systems, such as voltage control and protection, are based on the assumption that distribution systems are radial. Distribution Feeder Reconfiguration (DFR) is an optimization problem that search for the best feeder topological structure by managing the open/close status of sectionalizing and tie-switches to find a radial operating configuration that optimizes certain objectives while satisfying all the operational constraints without islanding of any node(s) [1]. DFR is a mixed integer non-linear optimization problem, since it should yield the open/close status of the sectionalizing and tie-switches as well as solving the non-linear power flow equations in the system.

Since past decade different approaches based on the mathematical optimization methods have been utilized to solve this problem [2,3]. DFR is not a continuous and convex optimization problem therefore applying mathematical based optimization methods such as Mixed Integer Non-Linear Programming (MINLP) are not straightforward and suitable to solve this problem. Recently convex relaxation of the DFR problem by Semi-Definite Programming (SDP) has attracted attentions since it can solve the DFR problem and obtain the global optima under specific conditions. SDP formulations create a convex relaxation of the DFR problem, the global optima of the relaxed DFR can be found in polynomial time under specific condition e.g. satisfying the rank-1 constraint. If the relaxed DFR can then be guaranteed to show a zero duality gap, the solution of the relaxed DFR must be the global optimum of the

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original DFR problem. The drawback of the SDP approach is handling the rank-1 constraint which is NP-hard. The rank-1 constraint can be found for some cases but there is no specific rule to handle this constraint generally which means that the SDP method cannot be able to find the global optima in some cases. Even though the SDP methods can find the global optima in some cases but these methods are in their infancy and a lot of studies need to be done to make them efficient and mature enough. Furthermore, convexification of a MINLP as well as computing the semi-definite bottleneck constraint are not easy tasks [2].

Other techniques that have attracted attentions during the past decade are Evolutionary Algorithms (EAs) which are flexible to solve any kind of optimization problems, and as long as the lower and upper bounds of control variables are known, they can solve any kind of the optimization problems irrespective of their characteristics and complexity. This characteristic makes the EAs a proper candidate for solving all kind of the optimization problems. EAs have been utilized to solve the DFR problem [4–9]. Even though they cannot guarantee to obtain the global optima or even show how much their solution close to the global optima, but their application to solve the optimization problems specially the NP-hard ones is getting increased because of their simplicity and finding an acceptable solution from the optimality point of view for many optimization problems. Furthermore, their ability of handling all type of constraints such as discontinuous functions has made them popular to be employed in discontinuous optimization problems [4]. Although these approaches are able to provide DFR solutions to a certain extent, yet there is scope for further bringing improvements in the methodology used as well as to speed up the execution process and therefore one of the goals of the present work is an attempt towards this direction [1].

Recently tones of studies have been dedicated to the operation of the distribution power system. Number of these studies is getting increased since emerging of Electric Vehicles (EVs), Distributed Generations (DGs), Energy Storage Systems (ESS) and the last but not least the smart grid implementation, which motivate researchers to study their effects on power system operation especially in distribution systems. *Rostami* et al. proposed an optimal stochastic reconfiguration methodology to ameliorate the charging effect of the Plug-in Hybrid Electric Vehicles (PHEVs) by changing the topology of the grid using some remote controlled switches [10]. Same authors introduced a DFR framework which employed as a reliability-enhancing strategy to coordinate Vehicle-to-Grid (V2G) provision of Plug-in Electric Vehicle (PEV) fleets in a stochastic framework. Uncertainties associated with network load demand, energy price, wind power generation, and PEV fleet behavior were considered [11]. *Kavousi-Fard* et al. presented a stochastic approach for the DFR in the smart grids with high penetration of PEVs and correlated wind power generation [12]. *Huang* et al. employed Mixed Integer Liner Programming (MILP) to obtain the optimal reconfiguration of distribution system under Dynamic Tariff (DT). Congestion management and line loss reduction in distribution networks were the objective functions and high penetration of EVs was also considered in the study [13]. *Malekpour* et al. proposed a multi-objective approach to solve Stochastic DFR (SDFR) problem for Wind Power Generation (WPG) and Fuel Cells (FCs) included system. A probabilistic power flow based on the Point Estimate Method (PEM) was implemented to capture uncertainty in the WPG output and load demand [14]. *Ding and Loparo* introduced an approach to study feeder reconfiguration for unbalanced distribution systems with DG resources. Sensitivity analysis and Non-Linear Programming (NLP) were employed to determine the three-phase bus locations and sizes of DG units. Also, distribution feeders were reconfigured every hour based on the status of time-varying loads, output power from DG units and faults on the network [15]. *Azizivahed* et al. developed a novel hybrid evolutionary algorithm i.e. Hybrid Modified Shuffled Frog Leaping Algorithm and Particle Swarm Optimization (MSFLA-PSO) to solve the multi-objective version of DFR problem on two different distribution systems considering power losses, Voltage Stability Index (VSI), and number of switching as fitness functions [9]. *Chen* et al. implemented hybrid PSO to solve the segmented-time DFR problem along with the segmented-time reactive power control of DGs in order to find the optimal dispatching schedule of all controllable switches and DGs' reactive power. A grouping branch method was utilized to simplify the formulation of mathematical problem [16]. *Larimi* et al. employed PSO algorithm to solve a risk-based DFR problem in presence of reward/penalty scheme and uncertainties in load and generation. Scenario based approach was implemented to capture risk modeling [17]. *Alonso* et al. presented a multi-objective Artificial Immune Systems (AIS) algorithm to reduce the power losses and improve the reliability index. Graph theory and Pareto-dominance mechanism were employed to improve computational performance and obtain Pareto-optimal solutions [18]. *Abdelaziz* proposed Genetic Algorithm (GA) with Variable Population Size, called GAVAPS algorithm, to solve the DFR problem in distribution systems [19]. *Ameli* et al. provided two different optimization algorithms including Ant Colony Optimization (ACO) and Harmony Search (HS) algorithms for solving the different model of DFR problem [20]. DFR at the presence of DG units is solved using GA by *Das* et al. [21]. *Fathy* et al. presented Binary PSO Gravity Search Algorithm (BPSOGSA) in order to solve the DFR problem considering reliability indexes [22]. A combination of a fuzzy multi-objective approach and Bacterial Foraging Optimization (BFO) algorithm was proposed by *Mohammadi* et al. in Ref. [23] to solve the DFR problem considering the effects of DG resources. *Niknam and Azad-Farsani* developed a hybrid configuration based on Self-Adaptive PSO (SAPSO) and Modified Shuffled Frog Leaping Algorithm (MSFLA), called SAPSO-MSFLA, for solving the DFR problem in distribution networks [24,25]. *Niknam* et al. proposed a hybrid EA based on combination of Fuzzy Adaptive PSO (FAPSO) and ACO, called HFAPSO algorithm, to solve the DFR problem [26]. *Niknam and Sha-Sadeghi* suggested Multi-objective Modified Honey Bee Mating Optimization (MMHBMO) algorithm to solve the DFR problem on 32-bus distribution system [27]. DFR problem along with capacitor placement was solved by Improved Binary PSO (IBPSO) algorithm in Ref. [28]. *Arasteh* et al. proposed PSO algorithm for solving the DFR problem considering Demand Response (DR) and uncertainties [29]. *Esmaeili* et al. developed Multi-objective Hybrid Big Bang-Big Crunch (MOHBB-BC) optimization algorithm to solve a multi-objective version of DFR problem in distribution systems considering operation cost, power loss, emission, and VSI [30].

Power system has encountered with more uncertainties in both generation and demand sides due to the intermittent, imperfectly predicted renewable energy, and uncertain load patterns. Besides electricity price has more variation due to the aforementioned factors which necessitate power system operators to adapt their methods for system analysis and operation. One common approach is extending the operational problems such as economic dispatch, optimal power flow, and DFR over multiple time intervals while taking the intertemporal constraint into consideration [31,32]. A common explanation for the split of DFR problems by time periods is that today's power systems require demands in a short time interval to be supplied, exactly, by generation within the same interval. Fortunately recent automation technologies integrated with communication systems and data analysis techniques make power system operators to operate as quickly as possible, and paves the way to the dynamically implementation of the power system operation problem. In this study, the DFR is solved as a dynamic