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Integrated DR and reconfiguration scheduling for optimal operation of microgrids using Hong's point estimate method

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ABSTRACT

The increasing penetration of renewable energy resources (RER) and their stochastic behaviors on the one hand and also, sharp fluctuations of electricity prices on the other hand have created substantial challenges for optimal operation of microgrids (MG). demand response (DR) programs associated with reconfiguration of MGs can provide feasible solution for this issue. Therefore, to address the aforementioned uncertainties in the optimal operation of MGs, this paper proposes an innovative Hong's 2m point estimate method (PEM) for simultaneously DR and reconfiguration scheduling with purpose to minimize the operating costs as well as to reinforce the reliability and resiliency of interconnected MGs in confronting with uncertainties. The Incentive-based model relies on interruptible/curtailable service (I/C) has been extended as DR program in the deregulated market. Meanwhile, an unprecedented dynamic reconfiguration problem has been optimally executed in order to reinforce the flexibility and robustness of MGs in confronting with diverse operating uncertainties. Finally, the proposed integrated model has been successfully solved by a population-based meta-heuristic algorithm namely exchange market algorithm (EMA). The simulation study is accomplished on the modified PG&E 69-bus distribution system over 24-h period. The obtained results demonstrate the usefulness and applicability of the proposed model.

1. Introduction

1.1. Motivation and aim

The concerns about global warming (greenhouse-gas emissions), scarcity of fossil fuels reserves, and primary energy independence of regions or countries have led to a dramatic increase of renewable energy resources (RER) penetration, mainly wind and solar power, in electric power systems. Owing to increasing influence of RERs in Microgrids (MG) and stochastic nature of market clearing price (MCP) in the deregulated power market environment, the distribution network operator (DNO) as responsible utility for optimal operation of MGs needs to manage the intermittence behavior of RERs to maintain the power balance between supply and demand [1,2]. Under these conditions, demand response (DR) programs associated with reconfiguration solution can significantly restrict the risk of uncertainty and thus provide considerable benefits for DNO and consumers such as reliability enhancement, operating cost reduction, reducing energy prices and amendment of technical specifications of distribution system [3]. The DR as defined by the U.S. department of energy, is the changes in pattern of energy utilization by end-user customers from their normal usage pattern in response to changes of electricity price over time, or to incentives/penalties to decrease high electricity consumption at high market price times as well as when the network reliability is at risk [4].

Accordingly, this paper mainly focuses on the incentive-based DR programs based on the interruptible/curtailable service (I/C). The proposed model for DR program considers penalties for end-user customers in case of no reaction to reduce their load consumption during peak load hours. Therefore, the clients are encouraged to reclaim their usage patterns to avoid penalty. In practical mode, the MCP during the peak hours is high and in the valley periods is low, so this pricing pattern motivates customers to reduce or shift their consumption during the peak load hours to the valley or off-peak hours. At first, the proposed model is extended by price elasticity of demand meaning, then the economic model for load pattern is calculated. The proposed DR program helps the DNO to recognize and apply related DR model that ameliorates the specifications of the load pattern.

On the other hand, one of the most important and practical solutions to increase the efficiency and performance of linked MGs is the reconfiguration problem that is the process of changing the topology of MGs by using some section switches (SSW) so that all of the operating and structural constraints are satisfied simultaneously [5]. In addition,

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to improve the usefulness and effectiveness of the proposed reconfiguration problem some tie switches (TSW) have been added on the network to increase the flexibility and resiliency of the MGs in the face of different operation uncertainties. These additional switches can modify the MGs connections to increase the network efficiency under different operating conditions, resulting in a dramatic improvement in the performance and interest of the proposed method [6].

The proposed dynamic reconfiguration problem schedules SSW and TSW in order to minimize the operating costs and improving technical features of MGs and also the utilized incentive-based DR program tries to increase the profit of system as well as to reinforce network reliability. Furthermore, the proposed integrated method will greatly affect the efficient operation and management of distributed energy resources (DER) installed on the network. Hence, to get the more benefits and also more comprehensive and impressive investigation, simultaneous scheduling of DR program and DER management considering reconfigurable structure for MGs seems very beneficial and fruitful because these two problems are complement each other. By the way, the demand side is connected to the supply side through a physical structure. Actually, simultaneous DR and DER management under reconfigurable topology is a win–win game for both DNO and consumers.

It should be noted that in the proposed problem, the existing uncertainty of parameters must be considered for the realization of a realistic solution. There are many methods available for uncertainty modeling that the best choice among them depends on many factors such as speed and accuracy of computational as well as the nature of uncertainty [7]. In so doing, this paper will get use of Hong's 2m PEM as a proper and straightforward method to cover the uncertainty of the investigated problem. The main motivations for utilizing Hong's 2m PEM approach are its accuracy, simplicity, and speed in implementation so that gives good results by using the same routines as in the associated deterministic problems, while keeping low the computational burden involved.

1.2. Literature review

In recent years, a wide range of studies has been focused on the DR programs as one of the best solutions in the demand side management (DSM). The DR programs can reduce the procurement costs of systems by reducing the energy consumption of costumers or shifting demand from peak hours to off peak in response to price, monetary incentives, or utility directives so as to maintain reliable electric service or avoid high electricity prices. Different references have investigated the DR scheduling in smart grids for miscellaneous goals.

Ref. [8] proposed a stochastic approach for daily reserve planning based on multi stage modeling by using demand response program. An incentive-based DR program as time of use model with dynamic economic dispatch problem is presented in [9] with aim to minimize the fuel cost and optimal incentive by random drift particle swarm optimization algorithm. In [10] a new multi objective economic-emission-related power dispatch problem is investigated based on game theory DR program with respect to the optimal hourly incentive. Ref. [11] proposed a novel nonlinear economic model for price-based responsive loads in distribution system. In this paper, a price-based methodology has been suggested for independent system operator (ISO) to find out more conservative model in participation of consumers in DR programs and the most economic model to optimal operation of smart distribution system. The study in [12] investigated an optimal residential management strategy relies on price-based DR associated with combined heat and power (CHP) units to minimize the daily operating costs with considering wind generation. A multi-objective approach is proposed based on coordination of both supply and demand sides in [13] with presence of DR and distributed generation (DG) units to maximize the benefits of operators as well as costumers with considering uncertainty. Ref. [14] analyzed an optimal day-ahead scheduling framework for optimal management of DER units in MGs with considering power flow constraints where the proposed model has been minimized through an integrated harmony-genetic algorithm. Also, a coordinated hierarchical DR model is suggested in [15] to control the performance of various DR programs in order to maximize utilization of available DR potentials by enabling simultaneous execution of multiple DR.

To maintain the availability of energy to the connected loads, considering priority and to interrupt the smallest portion of the MGs under any abnormal conditions, reconfiguration is critical to restore service to a section or to meet some operational requirements of dropping minimum loads. Reconfiguration is the process of modifying the MG's topological structure by changing the status (open/close) of the circuit breakers. Several references have analyzed reconfiguration problem in the MG based systems from different viewpoints. The study in [16] proposed a reconfiguration methodology for islanded MGs during faults mode with aim to increase the load ability of MGs and to decrease the power losses by applying multi-objective harmony search algorithm. Ref. [17] presented a stochastic reconfiguration solution to improve the reliability of distribution network and power loss reduction simultaneously by using the clonal selection algorithm. The reconfiguration of smart distribution network is performed for power loss reduction [18], reliability enhancing [19], improving load balance [20], voltage deviation [21] and optimum load shedding [22] by using various heuristic and meta-heuristic algorithms.

1.3. Contributions

To the best knowledge of the authors of this paper, there is no reference addressing simultaneously DR and reconfiguration scheduling for optimal energy management of MGs under uncertainty. To fill out this gap, this paper presents an innovative incentive-based DR program and dynamic reconfiguration model by utilizing Hong's 2m PEM from economic and reliability viewpoints. The main contribution of this paper is to model an integrated incentive-based DR program and DER management under reconfigurable topology where the uncertainty of the proposed problem is taken into account through carrying out a novel PEM approach. To this end, a cost-reliability based model is employed and subsequently has been solved with a population-based meta-heuristic algorithm namely exchange market algorithm (EMA). The concepts of proposed model to implement the integrated DR and dynamic reconfiguration in the multi-MGs based smart distribution system is shown in Fig. 1. Given the discussed context, the contributions of this paper can be summarized as:

- Optimally determining the merits and capacity of distribution buses (site/size) for participating in I/C based DR program.
- Determine the optimal amount of incentives and penalties for customers who have participated in the proposed DR program.
- Dynamic scheduling of installed switches to change the structure and communications of MGs to prevent the minus impacts of uncertainty on the profit of system.
- Coordinated energy management of existing DER units based on stochastic economic dispatch scheduling.
- Taking into account a new stochastic integrated model as MINLP formulation for proposed problem from economic, reliability and technical viewpoints.
- Considering the uncertainty of electricity prices and renewable power generation using Hong's 2m PEM approach to mitigate the risk of operating uncertainties.
- Adaption a fresh optimization algorithm so called EMA to solve the proposed model.
- Quantification the benefits of integrated DR and dynamic reconfiguration for profit maximization of multi-MGs for both DNO and costumers.