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The role of demand response in single and multi-objective wind-thermal generation scheduling: A stochastic programming

Hananeh Falsafi, Alireza Zakariazadeh, Shahram Jadid*

Center of Excellence for Power System Automation and Operation, Dept. of Electrical Engineering, Iran University of Science and Technology, P.O. Box: 1684613114, Tehran, Iran

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A B S T R A C T

This paper focuses on using DR (Demand Response) as a means to provide reserve in order to cover uncertainty in wind power forecasting in SG (Smart Grid) environment. The proposed stochastic model schedules energy and reserves provided by both of generating units and responsive loads in power systems with high penetration of wind power. This model is formulated as a two-stage stochastic programming, where first-stage is associated with electricity market, its rules and constraints and the second-stage is related to actual operation of the power system and its physical limitations in each scenario. The discrete retail customer responses to incentive-based DR programs are aggregated by DRPs (Demand Response Providers) and are submitted as a load change price and amount offer package to ISO (Independent System Operator). Also, price-based DR program behavior and random nature of wind power are modeled by price elasticity concept of the demand and normal probability distribution function, respectively. In the proposed model, DRPs can participate in energy market as well as reserve market and submit their offers to the wholesale electricity market. This approach is implemented on a modified IEEE 30-bus test system over a daily time horizon. The simulation results are analyzed in six different case studies. The cost, emission and multiobjective functions are optimized in both without and with DR cases. The multiobjective generation scheduling model is solved using augmented epsilon constraint method and the best solution can be chosen by Entropy and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods. The results indicate demand side participation in energy and reserve scheduling reduces the total operation costs and emissions.

1. Introduction

SG (Smart Grid) is an intelligent electricity network that uses information and communication technologies in the power system. Smart Grid technology could reduce many problems in the electric power industry such as limitation of fossil fuels and air pollution emission by using renewable energy resources [1]. It could be said that the wind energy plays the most effective role in the future of power generation, in comparison to other types of renewable energies. The electricity generation provided by wind farms is relatively cheap and the efficient way to reach air pollutants emission reduction goals [2]. But besides the above benefits, wind energy has variable and random nature and this problem imposes challenges to power system. To overcome this problem, power systems need some resources to compensate the wind power generation forecasting uncertainty. These resources are utilized to maintain the real time balance between production and consumption during operation of the power system.

In current power systems, ISOs (Independent System Operators) consider enough spinning and non-spinning reserves provided by generators for compensation of unpredictable nature of wind power [3]. Unfortunately these reserves generate emission, make some generating units be operated in non-optimal output and additional generators become committed [4]. In smart grid, ISOs have more options to make up for this uncertainty and reduce above problems. In other words, smart grid technologies help ISOs use DR (Demand Response) programs, energy storage units and plug-in electric vehicles beside reserves provided by generating units to compensate the random nature of wind power in a more efficient and cost-effective way [5].

End-use customers can decrease consumption, when the system faces a shortage in production caused by lack of wind, or increase it when the wind blows is high. So, these responsive

* Corresponding author. Tel.: +98 21 77491223; fax: +98 21 77491242.
E-mail addresses: hananeh_falsafi@elec.iust.ac.ir (H. Falsafi), zakaria@iust.ac.ir (A. Zakariazadeh), jadid@iust.ac.ir (S. Jadid).

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loads provide reserve and reduce the amount of reserve provided by generating units. In addition to providing reserve, responsive loads can also participate in energy markets and compete with generator production. Providing energy by these loads reduces cost and emission of generating units. This End-use customer participation which is called demand response can help power system to be more efficiently, economically and securely operated. DR programs are classified into two major categories: price-based and incentive-based DR programs. First category programs refer to change in electricity consumption by end-use customer in response to dynamic prices. These programs include TOU (Time of Use) rate, RTP (Real Time Pricing), and CPP (Critical Peak Pricing) and are entirely voluntary. To access price signals, two-way communication link between the consumer and supplier is necessary that AMI (Advanced Metering Infrastructure) system provides it [6,7]. Second category programs are designed by operators and include Direct Load Control, Interruptible/Curtailable service, Demand Bidding, Emergency DR, Capacity Market, and Ancillary services market program. These programs give participating customers incentive payments and can consider penalties for customers that enroll but do not respond in needed time, depending on the program types and conditions. Fig. 1 shows classification of DR programs. These DR programs are discussed in more detail in Ref. [8].

In recent years, many researches have been worked on covering uncertainty of wind power. In Ref. [9] a stochastic programming has been used for market clearing and considered load and wind prediction error as normal distributed random variables. In Ref. [10], a method for dealing with the short-term active power scheduling of a stand-alone system has been presented. In this method, the fuel cost of diesel units and CO_2 emission are minimized while the operation constraints are satisfied. Moreover, the maximum wind and solar PV powers with uncertainties are modeled using fuzzy sets. In Ref. [11], the wind prediction error is modeled by a PDF (probability density function) and used spinning reserve provided by generation units for covering uncertainty of wind power. In Ref. [12], a modified teaching-learning algorithm has been proposed to cope with a probabilistic multiobjective wind-thermal dispatch problem. The economic/environment dispatch model has considered the uncertainties in load demand and wind speed as input random variables of the systems. However, the demand side participation is not taken into account in the paper.

In addition to spinning and non-spinning reserve, demand response can also help ISOs and compensate random nature of wind power. In Ref. [13] price-based DR is used to change the consumption of end-user customers when wind blow is different from its predictive value. In this paper, demand is a function of price in each period, so it has different behaviors in various times. Unfortunately, price-based DR programs are voluntary and if customers do not respond in needed time, some problems on power system will be imposed. The impact of demand side management strategies on the power system operation with high penetration of renewable energy sources has been analyzed in Ref. [14]. The results have evidenced that demand side management strategies can lead to a significant delay in the investment in new generation capacity and improve the operation of the existing installed capacity. In Ref. [15], an incentive-based DR program is proposed that reshapes the system load and so helps to integrate wind generation. This is not a stochastic programming method and the DR program used in this reference only provides load reduction. In Ref. [16], the imposed costs that are caused by wind generation uncertainty have been examined in three cases. The first case has used RTP program [17], in the second one, variable wind power has been modeled by scenario tree and the third has combined the two above cases. Although all of them reduce costs, the first one is more effective than the second and the third case is the most successful in cost reduction.

In present paper, a two-stage stochastic programming is utilized to minimize total operating cost and air pollutants emission, separately and simultaneously. The proposed model schedules energy and reserves provided by both of generating units and responsive loads. In the presented model, ISO receives DR quantity and its offered price from DRPs (Demand Response Providers). Price-based DR also is modeled by price elasticity concept of the demand. The multiobjective generation scheduling model is solved by using augmented epsilon constraint method [18]. The best solution can be selected by Entropy and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods.

The rest of this paper is organized as follows. In Section 2 market structure and the proposed DR programs are introduced. The DR programs models are described in Section 3. The program formulation is presented in Section 4. In Section 5 the multiobjective wind-thermal generation scheduling and also epsilon constraint, Entropy and TOPSIS methods are introduced. Case study is discussed in Section 6, and conclusions are given in Section 7.

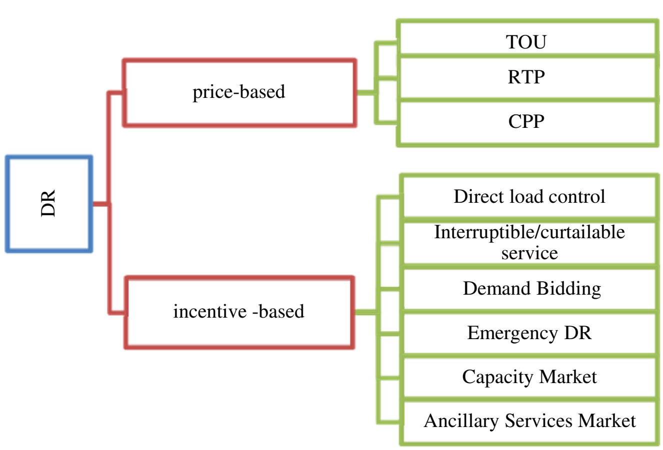

Fig. 1. Classification of demand response programs.

2. Problem description

2.1. Market structure

In this paper, a day-ahead market is used that its structure is shown in Fig. 2. As can be observed in this figure, ISO receives bids from GENCOs (generating companies) and DRPs for providing energy and reserves. Also, ISO will be aware of hourly demands by DISCOs (distribution companies). Moreover, some customers will alter their consumption after receiving price signals. Note that customer response to price signals is entirely voluntary, but for the sake of simplicity, it is assumed that costumers will change their consumption with respect to electricity prices. Finally, ISO will simultaneously schedule energy and reserves in a power system with high penetration of wind power by considering above items, transmission system constraints and different objective functions.

2.2. Demand response

As already mentioned, DR programs are divided into incentive-based and price-based DR programs. In this paper two incentive-based DR programs have been used that ancillary services market

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