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A dynamic economic emission dispatch considering wind power uncertainty incorporating energy storage system and demand side management

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ABSTRACT

Reducing carbon emissions is an important goal for the whole world; a high penetration of wind energy can help in reducing emissions. However, great increase in wind energy usage raises some issues concerning its variability and stochastic nature. These issues increase the importance of studying methods of wind energy representation, and in the same time studying the effect of using some flexible resources in decreasing those issues. This paper proposes a dynamic economic emission dispatch (DEED) model incorporating high wind penetration considering its intermittency and uncertainty. Energy storage system (ESS) and demand side management (DSM) are implemented in order to study their effect on the cost, emission, and wind energy utilization. The GAMS software has been utilized to solve this DEED problem. The achieved results show the importance of using ESS and DSM in decreasing both cost and emission, and increasing the wind energy utilization.

1. Introduction

Using wind energy as a renewable resource has numerous advantages as it is a clean energy resource with low running cost; which in turn encourages governments to increase the sharing percentage of wind energy. The wind speed is naturally stochastic; this leads to uncertainty and intermittency in wind power output. In case of high penetration of wind energy, there is a strong need for proper representation of wind power and flexible resources facilitating this high penetration of wind energy. The conventional method of wind power representation is using the average values of wind power (WP) as presented in Refs. [1–3]. But the probabilistic infeasibility of using average WP is high; in range of 0.75, so representing the WP as a chance constraint in the model can handle the uncertainty in WP as introduced in Refs. [4–6].

Mainly, there are two types of flexible resources; Energy Storage System (ESS) and Demand Side Management (DSM). In different researches, wind energy has been studied within the power system accompanied with those flexible resources. The incorporation of ESS with high penetration level of wind energy into a unit commitment model has been studied in Refs. [7–9]. In Refs. [10–13], the utilization of demand response with high wind power penetration level has been studied through a unit commitment problem. In Refs. [14,15], the incorporation of both demand response and ESS with wind energy has been studied within a unit commitment problem. Large scale wind power penetration has been studied through a dynamic economic dispatch (DED) model in Refs. [6] and [16]. The impacts of utilizing wind energy within an economic load dispatch (ELD) have been studied in Refs. [1] and [4].

All the previous works published in Refs. [1–16] have only dealt with minimizing operation cost; however, in recent days governments give greater emphasis to environmental aspects and clean air, and new regulations and policies have been raised to limit pollution. Nowadays it is crucial to simultaneously study both emissions and cost. The references [5,17–20] have studied both cost and emissions. An emission minimization model is proposed in Ref. [5] for a system of high penetration of wind energy, when the probability of stochastic wind power is presented as a constraint avoiding the probabilistic infeasibility coming from representing wind power through average values of random variables. In Refs. [17], a multi-objective stochastic search algorithm is implemented to investigate the probabilistic economic emission dispatch problem considering both underestimating and overestimating available wind energy. An efficient algorithm is introduced in

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Ref. [18] for dealing with economic power dispatch problem by combining two meta-heuristic methods, which are the firefly algorithm and the micro genetic algorithm. Different cases are studied such as: minimizing fuel cost and emissions; both individually and simultaneously, as well as the effect of incorporating high level of wind energy. In Refs. [19], DEED simultaneously minimizes the emissions and total cost over a 24 h time span; a modified particle swarm optimization algorithm is utilized to get the best solution. Multi − objective evolutionary algorithm based on decomposition as a new optimization technique has been utilized to optimize emissions and cost of wind-thermal power system in Ref. [20].

From the above literature, it is obvious that there is no study taking into consideration the incorporation of flexible resources such as ESS and DSM programs, measuring their effect on both cost and emission calculations considering variability and uncertainties in wind power. So this paper proposes a DEED model incorporating ESS and DSM program when the high level of wind energy penetration is considered as a chance constraint. The paper focuses on the optimal operation of power systems. Accordingly, the cost of both ESS and DSM program are not considered in the paper analysis. The effect of using those different resources have been extensively studied through four main different scenarios to assess the effect of utilizing one or both of them on wind energy utilization, the cost and emission.

This multi objective problem has been converted for paper work to a single objective problem using a linear combination of the two objectives via the weighted sum method, in which the Pareto front (PF) have been gotten by changing the weighting factor. GAMS software using BARON solver has been utilized to solve this DEED problem. Genetic Algorithm (GA) with hybrid function (*fmincon)* has just been utilized to double check the model data. The different tested scenarios confirm the great value of utilizing the ESS or DSM to decrease both the cost and emission and increase the wind energy utilization; however, the best outcome results from using both ESS and DSM.

2. Modeling approaches

The proposed DEED formulation including high penetration of wind energy, DSM and ESS is modeled through the Equations from (1) to (19); such equations will be discussed in details in the next subsections. Meanwhile, Fig. 1 shows a quick view on the overall proposed DEED formulation components and also summarizes the equations used in modeling each component.

2.1. Dynamic economic emission dispatch (DEED)

Dynamic economic emission dispatch (DEED) is an extension to the economic emission dispatch model through considering the ramp rate limits for the thermal units. The DEED is a multi-objective problem with opposing objectives as emission minimization conflicts with fuel cost minimization. DEED objective is to simultaneously minimize the cost and emission and satisfying some constraints in order to get the power outputs of the generators over a certain period of time. Eqs. (1)–(3) describe such objective function. It is worth mentioning that the overall cost which is presented by the single objective problem is used here to represent the multi objectives problem using the weighted sum method, in which the change of weighting factor is used to get the optimal Pareto front. Eqs. (4) and (6) describe the stochastic chance constraint that represents the wind power, Eq. (7) states the minimum and maximum wind power, Eq. (8) states the minimum and maximum generation capacities and finally Eqs. (9) and (10) show the ramping up and down constraints.

Minimize:

$$F_T = \omega \times F_1 + (1-\omega) \times F_2 \tag{1}$$

$$F_1 = \sum_{t=1}^{T}\sum_{g=1}^{G} a_g P_{gt}^2 + b_g P_{gt} + c_g \tag{2}$$

$$F_2 = \sum_{t=1}^{T}\sum_{g=1}^{G} \alpha_g P_{gt}^2 + \beta_g P_{gt} + \gamma_g \tag{3}$$

where:

F_T: is the overall cost.
ω: is the weighting factor.
F_1: is the total cost of operation.
F_2: is the total emission.
P_{gt}: is the real power generated by gth generator during interval t.
a_g, b_g andc_g: are the cost coefficients of the gth generator.
α_g, β_g andγ_g: are the emission coefficients of the gth generator.
T: is the number of dispatch intervals in the dispatch period.
G: is the total number of thermal generators.

Subject to:

$$\Pr\left(\sum_{g=1}^{G} P_{gt} + Pw_t \le L_{dold,t} + P_{Losses,t}\right) \le \alpha \tag{4}$$

where:

Pr (U): is the probability of an event U.
Pw_t: is a random variable that represents wind power during interval t.
$L_{dold,\ t}$: is the total load demand without using DSM during interval t.
$P_{Losses,\ t}$: are the transmission system losses during interval t.
α: is a specified threshold representing the tolerance that the total load cannot be satisfied.

It is worth mentioning that selecting the value of α represents the tradeoff between the utilization of wind energy and the associated risk. When alpha is chosen high, the system operator relies more on the wind energy and less on the thermal units, and vice versa. Accordingly, for very low alpha, no wind energy will be considered.

$$P_{Losses,t} = \sum_{g=1}^{G}\sum_{j=1}^{G} P_{gt} B_{gj} P_{jt} \tag{5}$$

where:

P_{gt}: is the real power injections at gth bus at time t ($t = 1, 2 \ldots.$ T).
P_{jt}: is the real power injections at jth bus at time t ($t = 1, 2 \ldots.$ T).
B_{gj}: are the loss coefficients.

By considering Weibull probability distribution function of wind power [4]: