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A fuzzy chance-constrained program for unit commitment problem considering demand response, electric vehicle and wind power

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ABSTRACT

As a form of renewable and low-carbon energy resource, wind power is anticipated to play an essential role in the future energy structure. Whereas, its features of time mismatch with power demand and uncertainty pose barriers for the power system to utilize it effectively. Hence, a novel unit commitment model is proposed in this paper considering demand response and electric vehicles, which can promote the exploitation of wind power. On the one hand, demand response and electric vehicles have the feasibility to change the load demand curve to solve the mismatch problem. On the other hand, they can serve as reserve for wind power. To deal with the unit commitment problem, authors use a fuzzy chance-constrained program that takes into account the wind power forecasting errors. The numerical study shows that the model can promote the utilization of wind power evidently, making the power system operation more eco-friendly and economical.

Introduction

Wind energy is deemed to be a significant future alternative to conventional energy resources, such as fossil fuels [1]. But there are still some crucial obstructers for the effective utilization of wind generation [2,3]. From the point of view of dispatching, wind power output not only is uncertain and intermittent, but also has a serious time mismatch with load demand during a day. For example, wind has the possibility to be relatively abundant during the night when the load demand level is in its valley period [3].

As a crucial step for power system operation, unit commitment (UC) is to determine the on/off statues and the output of each generator units for the next day [3]. Traditionally, power supply-demand balance is achieved by scheduling generator units to meet power demand. With the development of smart grid, elements in demand side, such as demand response (DR) and electric vehicle (EV), are able to play an increasingly important role in power system. Some researchers have considered them together with traditional generators in supply side [4–6]. DR and EV are flexible and low-carbon elements. They may also be economical compared with traditional power generation, especially during the peak-load hours [7,8].

It is a good idea to make advantages of DR and EV to facilitate the utilization of wind power. Although a great quantity of scholars have done some meaningful researches on the promotion of wind power utilization [1,9–11], there are still few relevant researches doing the work by virtue of DR and EV. In [12], a multi-stage robust UC model has been presented considering DR to ensure the reliability requirement of the grid while making use of wind power. In [13], polytropic uncertainty set has been used in its UC model to capture the wind uncertainty taking into account its interactions with DR. In [14], the storage capacity of EV is researched to mitigate the variability of renewable energy resources. In [15], charging and discharging of EV with wind power are utilized in UC to minimize the total power system operation cost and emission. However, most of the researches do not pay much attention to the time mismatch with load demand, which is a typical feature of wind power resources. Moreover, few researches consider DR and EV together to make the most advantage of demand side resources for the effective integration of wind power.

Authors propose a fuzzy chance-constrained UC model considering DR, EV and wind power. We focus on the effects of DR and EV on the promotion of wind power utilization. The numerical study including five scenarios shows the effects of DR and EV on changing load demand curve to match wind power output and

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on relieving the reserve requirement stress caused by wind power penetration. In addition, authors also analyze the impact of confidence level on the results of UC.

The reminder of this paper is divided into the following sections: Section 2 describes how DR and EV are taken into consideration. Section 3 presents our chance-constrained UC optimization model. Section 4 introduces the modified PSO algorithm to solve the optimization problem. Section 5 introduces our numerical studies and analyzes the results, followed by conclusions in Section 6.

Demand response and electric vehicle in unit commitment

Demand response

Demand curtailment and demand shifting are two typical forms of DR [8].

Demand curtailment

This kind of DR can be treated as avoidable load. Electricity consumers may curtail parts of their power demand if they are given enough financial compensation. A crucial point here is to determine the relationship between the amount of compensation and demand curtailment. Authors believe that the marginal cost of demand curtailment will rise with the amount of curtailment increasing. This cost in UC problem is presented as a quadratic function of curtailment as in (1).

$$C_{DRc}(DRc_t) = a_{DRc} + b_{DRc}DRc_t + c_{DRc}DRc_t^2 \qquad (1)$$

where DRc_t is the amount of demand curtailment at time t, a_{DRc}, b_{DRc}, c_{DRc} are cost coefficients. Upper limits of the curtailment at each hour and the accumulated curtailment within a day are defined in (2) and (3) respectively.

$$DRc_t \le DRc_{t,max} \qquad (2)$$

$$DRc = \sum_{t=1}^{24} DRc_t \le DRc_{max} \qquad (3)$$

Demand shifting

The other typical form of DR is demand shifting. Electricity consumers may shift parts of their power demand to other hours according to the financial compensation. For example, residents can actually use their dishwashers either in the evening or after midnight. But for the sake of power system and the integration of wind power, it is better to shift this part of load to hours early in the morning if the wind power output is relatively high during that time. Similarly, the cost of demand shifting in UC problem is treated as a quadratic function.

$$C_{DRs}(DRs) = a_{DRs} + b_{DRs}DRs + c_{DRs}DRs^2 \qquad (4)$$

where DRs is the amount of demand shifting among different hours, a_{DRs}, b_{DRs}, c_{DRs} are cost coefficients of demand shifting.

Obviously, only parts of the power load can be shift to another time within a certain period. This paper has considered three typical sorts of power demand shifting as listed in Table 1 [16].

Table 1
Chief sorts of shiftable power demand.

No.	Typical appliances	From	To
1	Washing machines and dishwashers	20–23	24–3
2	Cold appliances	12–13	10–11
3	Water heaters	18–19	16–17

It is assumed that different kinds of demand shifting have different cost coefficients. So Eq. (4) should be rewritten as follows.

$$C_{DRs}(DRs) = \sum_{i=1}^{n} C_{DRs_i}(DRs_i) = \sum_{i=1}^{n}\left(a_{DRs_i} + b_{DRs_i}DRs_i + c_{DRs_i}DRs_i^2\right) \qquad (5)$$

where n is the number of sorts of demand shifting, which is 3 in this paper, DRs_i is the total amount of each sort of demand shifting among different hours within a day, a_{DRs_i}, b_{DRs_i}, c_{DRs_i} are cost coefficients of each sort of demand shifting.

DRs can be accumulated as follows:

$$DRs = \sum_{i=1}^{n} DRs_i = \sum_{i=1}^{n}\sum_{t=1}^{H} \max\left(0, DRs_{i,t}\right) \qquad (6)$$

$$DRs_t = \sum_{i=1}^{n} DRs_{i,t} \qquad (7)$$

where H is the total number of hours to be studied, which tends to be 24, $DRs_{i,t}$ is the net load demand shifting of each sort out of time t, DRs_t is the aggregate net load demand shifting at time t. $DRs_{i,t}$ and DRs_t can be either positive or negative. They mean the load shifting to other hours if they are positive, while they mean the load shifting from other hours to this hour if they are negative. Evidently, we have the following equations.

$$\sum_{t=1}^{H} DRs_{i,t} = 0 \qquad (8)$$

$$\sum_{t=1}^{H} DRs_t = 0 \qquad (9)$$

Upper limits on $DRs_{i,t}$ and DRs_i are set as follows.

$$\left|DRs_{i,t}\right| \le DRs_{i,t,max} \qquad (10)$$

$$DRs_i \le DRs_{i,max} \qquad (11)$$

Electric vehicle

Undoubtedly, EV will play an important role in power system because it will bring about a great amount of power demand and it also can serve as power source to the grid if needed.

Smart charging

Smart charging means EVs does not charge only as users' please. On the contrary, this part of load may be shifted to other time within a period according with the system operators' wishes if they have signed contracts with power users. This paper assumes that the charging load has been already contained in original load demand in UC problem, and the shiftable charging load is formerly within 18–23 o'clock. System operator may shift part of the load to 2–7 o'clock after midnight if necessary. This mode of EV can actually be regarded as a special form of DR. The cost of smart charging in UC is considered as a quadratic function, too.

$$C_{EVc}(EVc) = a_{EVc} + b_{EVc}EVc + c_{EVc}EVc^2 \qquad (12)$$

where EVc is the amount of charging load shifting among different hours, a_{EVc}, b_{EVc}, c_{EVc} are cost coefficients. EVc can be accumulated as in (13).

$$EVc = \sum_{t=1}^{H} \max(0, EVc_t) \qquad (13)$$

where EVc_t is the amount of net EV charging load shifting out of time t. Similar to DRs_t, the value of EVc_t may be either positive or negative depend on whether the charging load is shifted out of or into time t. We have the following equation.