Day-ahead Scheduling of Islanding Microgrids Based on Wind Power Forecast

Yusang Chen1,* and Minfang Peng2

1Hunan University, College of Electrical and Information Engineering, Changsha, China
2Hunan University, College of Electrical and Information Engineering, Changsha, China

Abstract. Wind power, as the main energy source of the island microgrid, has uncertain output. Reasonable setting of TOU price can improve adaptability to changes in wind power output. Based on the time series characteristics of wind speed, the EWMA is used to predict the wind speed day-ahead. Then through the method of distribution superposition fitting and roulette, the day-ahead forecast data of wind power considering power fitting error is obtained. As a reference, a new TOU price division method based on wind power output is proposed. At the same time, P2G and energy storage devices were introduced into the cogeneration system to achieve Gas-electric transformation functions. Combined with the heating and electric demand response of the user side, comprehensively considering the mutual conversion relationship between multiple energies. On the premise of considering economy and environmental protection, the Gurobi solver is called by Yalmip to get the start-stop status of the power-side unit and the user-side unit.

1 Introduction

Wind energy is the main energy of islanding microgrid [1-3]. The accuracy of wind power prediction will affect the reliability and stability of islanding microgrid. Paper [4-5] use a known distribution model to fit the probability distribution curve of wind power, and then predict the wind power output based on its distribution probability. The error between the predicted result and the actual output will be relatively large. Without the support of the power grid, how to maintain the energy demand of the user side on the premise of ensuring the real-time energy balance of the supply and demand side is an urgent problem to be solved. The emergence of a comprehensive energy system has realized the conversion and utilization of energy [6], improving the energy utilization efficiency. And with the birth of P2G, it can convert excess electrical energy into natural gas for storage, and realize the time transfer of energy [7-8].

These studies have maximized energy use through comprehensive optimal scheduling of multi-energy complementary systems. However, in the case of isolated islands, wind power is the main energy supplier, and the output of wind power cannot be artificially allocated. Therefore, it is difficult to achieve the real-time balance of supply side and the demand side relying on the optimal scheduling of energy supply units. At present, many researches focus on the supply and demand side joint scheduling considering the comprehensive energy system and demand response [9-11]. However, existing studies usually consider the time-of-
use electricity price or provide compensation price based on the response amount when considering the user-side demand response. Few studies have considered the relationship between demand response and wind power output.

In response to the above problems, this paper builds a power supply model framework including P2G and multiple energy storage equipment. The wind speed is predicted by EWMA. The wind power error distribution is fitted in different wind speed segments, and then the reject sampling and roulette method are used to obtain the day-ahead forecast data based on the power fitting error. Considering that the traditional TOU price is fixed and the wind power output curve is random. By designing a electric price division method to calculate the TOU price, the electricity price can follow the change of wind power output.

2 Day-ahead forecast of wind power

It is known that wind speed is related to recent data, and the closer the time distance, the greater the degree of data correlation. Therefore, EWMA is used for wind speed prediction.

\[
\hat{v}_{t-N+1} = \lambda \cdot v_t + (1-\lambda) v_{t-1} + \cdots + (1-\lambda)^{N-1} v_{t-N+1}
\]

where, \(\hat{v}_{t-N+1}\) is the forecast value of wind speed; \(v_t\) is actual wind speed; \(\lambda\) is weight coefficient; \(N\) is the forecast period.

Based on the historical data of wind speed and wind power, a classic stand-alone model is used to fit the wind speed-wind power characteristic curve \([5]\). Divide the cut in wind speed to the rated wind speed into 1m/s segments, and then fit the power error distribution in sections. Because of the irregular distribution of wind speed error, the probability density function of different wind speed segments is obtained by the method of superposition distribution fitting.

The power fitting error is sampled by the rejection sampling method, and the error probability obtained by the sampling is normalized. By using the roulette method, the power fitting errors of different wind speed segments are selected, and the day ahead forecast data of wind power considering the power fitting errors are obtained.

3 Demand response

The division of TOU prices encourages people use more electricity during peak periods of wind power and less during periods of low wind power. Normalize the wind power forecast data and map it to the interval \([0 \ 1]\). In order to obtain the electricity price curve that is opposite to the characteristics of the wind power output curve, the normalized wind power output curve is shifted up units and then the reciprocal is taken. At the same time, according to the specified price range \([a \ b]\), the scale is \(\delta\). The starting point of TOU price is controlled by \(\mu\) and the range of TOU price is controlled by \(\delta\).

\[
\frac{\delta}{P_{w,\text{max}} - P_{w,\text{min}}} + \mu 
\]

where, \(P_{w,\text{min}}\) is the minimum value of wind power output; \(P_{w,\text{max}}\) is the maximum value of wind power output.

Consider the conversion relationship between the temperature change of residential users and the heat gain. The user provides a temperature comfort zone, and the energy supply side units reasonably arrange the output according to the temperature comfort zone.

\[
Q_{\text{load}} = \sum_{t=1}^{T} \sum_{h=1}^{H} Q_{1.1.h} + \sum_{n=1}^{N} \sum_{t=1}^{T} (Q_{1.1.H} + Q_{1.1.INF} + Q_{1.1.H1})
\]
where, $Q_{load}$ is the heat demand; $Q_{I.t.h}$ is the heat consumption per household; $I$ is the number of residents; $Q_{I.t.H}$ is the heat dissipation from indoor to outdoor; $Q_{I.t.INF}$ is the heat dissipation caused by ventilation; $Q_{I.t.H1}$ is indoor heat gain.

The calculation expressions of $Q_{I.t.h}$ and $Q_{I.t.INF}$ refer to paper [13]. In order to meet the user's thermal comfort, the indoor temperature needs to be constrained in a range.

The electrical equipment of residential users is divided into three categories: non-interruptible and non-transferable, non-interruptible and transferable, and interruptible and transferable, which are simulated separately.

The allowed operating period of non-interruptible and non-transferable equipment is its working period. The working period of the uninterruptible and transferable equipment is included in its allowed operating period, and it can only work continuously. The interruptible and transferable device can work at any time within the allowable operating period, and only needs to meet the working hours within the allowed operation period.

4 Day-ahead scheduling for isolated microgrid

The framework structure of the cogeneration system constructed in this paper is shown in Figure 1. Energy input: wind power and natural gas. Energy conversion equipment includes: gas turbines (GT), gas boilers (GB), fuel cells (FC), P2G and ground source heat pumps (HP). Energy storage equipment: battery, gas storage tank (GS) and heat storage device (HS). The energy output forms are: electrical and heat. The cogeneration system is in an island operation mode and has no energy interaction with the power grid. The model references of various equipment in the paper [6].

Considering the day-ahead scheduling model of islanding, the interests of both the user side and the power side should be taken into account. The goal of the user side is to optimize the economy, which includes two items: electricity fee $C_{fee}$ and heating fee $C_{H}$.

The energy supply side needs to take the environmental protection into account while considering the economic operation of the unit. Pay attention to the wind power consumption and Greenhouse gas emissions. The energy supply side needs to consider gas cost $C_R$ the unit operation and maintenance cost $C_Y$, the penalty for wind abandonment $C_W$, the greenhouse gas emission treatment costs $C_{CO2}$, the penalty for load-cut $C_{cut}$.

The constraints of the model mainly include: system energy balance constraints, load side constraints and power supply equipment constraints.

System energy balance includes electrical balance and heat balance.

$$P_{wind}(t) + P_{GT}(t) + P_{FC}(t) = P_{HP}(t) + P_{ps.c}(t) + P_{P2G}(t) + P_{load}(t) + P_{loss}(t)$$

(4)

$$Q_{GT}(t) + Q_{GB}(t) + Q_{HP}(t) + P_{hs.d}(t) = P_{hs.c}(t) + Q_{load}(t) + Q_{conv}(t)$$

(5)
The constraints for heat and electrical loads are described in heat and electrical demand. The output of GT and GB shall not exceed their rated power and the climbing speed shall be within the allowable range. P2G, FC and HP are mainly limited by capacity. Energy storage devices cannot charge and discharge energy at the same time. They are also limited by capacity. In addition, the energy stored in the energy storage device should be equal to the beginning for the next day.

5 Example analysis

The example of this paper does not consider the operation and maintenance cost of energy storage equipment. The energy supply unit data, system operation data and user side equipment data consult paper [2][6][14].

Wind power and wind speed data use historical data from a certain region of China. The wind speed distribution follows Weibull distribution. The fitting result of the wind farm power characteristics obtained through simulation is shown in Fig 2. The results of power error distribution at different wind speeds are shown in Figure 3. The comparison between the wind power output curve and the electricity price curve is shown in Figure 4. Randomly select three groups of wind power output data and calculate the TOU price of each group of data, as shown in Figure 5. Comparing the scheduling results of the three-component electricity price and the fixed TOU electricity price, as shown in Table 1.

<table>
<thead>
<tr>
<th>Scene</th>
<th>$P_{\text{wind}}/\text{MW}$</th>
<th>$C_{\text{pv}}/\text{yuan}$</th>
<th>$C_{\text{co}}/\text{yuan}$</th>
<th>$C_{\text{c}}/\text{yuan}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25340.7</td>
<td>3116.7</td>
<td>523.8</td>
<td>21614</td>
</tr>
<tr>
<td>2</td>
<td>25331.9</td>
<td>3786.5</td>
<td>546.9</td>
<td>21746</td>
</tr>
<tr>
<td>3</td>
<td>25326.2</td>
<td>3507.8</td>
<td>542.9</td>
<td>21724</td>
</tr>
<tr>
<td>4</td>
<td>25296.2</td>
<td>3575.9</td>
<td>548.5</td>
<td>21767</td>
</tr>
</tbody>
</table>

It can be seen from Table 1 that the TOU price division method designed in this paper can not only reduce the electricity cost on the user side, increase the level of wind power.
consumption, but also reduce the purchase volume of CO₂ and emissions of natural gas. When the fixed TOU price is used, the valley period of the electricity price corresponds to the valley period of the wind power output. During the operation period of the equipment, the shortage of wind power output can only be compensated by shifting the equipment to the high electricity price period for operation or purchasing natural gas. In the case of insufficient wind power, GT discharges CO₂ during operation and there is no extra power in the system for P2G to convert natural gas and consume CO₂, which increases energy costs and CO₂ emission.

6 Conclusion

In this paper, wind power forecast is carried out on the basis of wind power fitting error, and a new TOU price division method considering wind power output trend is designed according to the prediction results. The introduction of a combined heat and power system with P2G and multiple energy storage devices and demand response strategies in the model is conducive to increasing wind power utilization and reducing costs on the supply and demand side.

The example results show that, compared with any fixed TOU price, the new TOU price division method designed in this paper can effectively improve the capacity of wind power consumption, reduce the user side costs and greenhouse gas emissions. Get better scheduling results in terms of economy and environmental protection.

References

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