The Power Output Characteristics of Jiuquan Wind Power Base and Its Reactive Power Compensation

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Abstract—The second phase of Jiuquan wind power base in China has been built with 3GW of first batch. This paper deliberately researches its power output characteristics based on the observation data in 2012, which provide technical reference for further work of power grid planning. Moreover, on the basis of northwest China grid data package in Power System Analysis Software Package (PSASP), this paper compares the voltage control effect under different reactive power compensation schemes after the second phase wind farms integrated. Analysis results indicate that wind power output characteristics in Jiuquan are obviously random and low. The power output change rate is low as well. As for reactive power compensation strategies, centralized compensation at low voltage side is better than dispersed compensation to control system voltage. Finally, choosing reactive power compensation devices and reactive power allocation schemes rationally can maintain the system voltage both effectively and economically.

Index Terms—Wind power generation; Second phase of Jiuquan wind power base; Power output characteristic; Reactive power compensation

I. INTRODUCTION

Wind energy resources of Gansu province mainly concentrates in Hexi corridor. Jiuquan locates at the western end of Hexi corridor among 92°00’~100°30’ east longitude and 37°51’~42°50’ north latitude with a total area of 19.2 square kilometers, which contains abundant wind resources [1]-[3].

Jiuquan wind power base in Gansu province is the first tens of million kilowatt class wind power base in China. The total wind energy resource is about 237 million kW with 39.98 million kW exploitable. In 2011, the installed wind power capacity reached 5409.2 MW [4], becoming the 3rd largest wind power base in China. By now, grid-connected installed capacity reaches 5802 MW, which accounts for 22.3% of gross installed capacity in Gansu province. More than 40 wind farms have connected to grid.

Wind energy is of randomness and volatility. Analyzing wind power output characteristics has significance benefit for better utilization of power resources and the cooperation of power grid and wind farms. Moreover, the weak frame structure of the grid around the connected point of wind power may affect the voltage stability [5]-[9] of the integrated power system. Therefore, how to improve the voltage stability of power grid with wind power has become one of the key issues for Gansu power grid.

By analyzing the observation data in 2012 of 18 wind farms in Jiuquan (taking 1h as time interval, every wind farm has 365*24=8760 observation points), the power output characteristics of the Jiuquan wind power base are illustrated in this paper.

In allusion to possible voltage stability problems, the impact of wind power interfacing is researched on the basis of winter operation mode data package in Power System Analysis Software Package (PSASP). Meanwhile, voltage control effect under different reactive power compensations are compared and discussed.

II. CHARACTERISTICS OF JIQUAN WIND POWER

A. Wind Power Output Distribution

1) Wind power output

The relative power output is defined as,

\[
\sigma_{ijk} = \frac{\sum_{n=1}^{18} P_{ijk}^{(n)}}{\sum_{n=1}^{18} P_{n \text{install}}^{(n)}}, \quad i \in (1, 2,...,12), j \in (1, 2,...,31), k \in (1, 2,...,24)
\]

Where \(\sigma_{ijk}\) is wind power output of Jiuquan wind power base. Subscript \(i\), \(j\) and \(k\) represents the month, day and hour respectively. \(P_{ijk}^{(n)}\) is the output active power of the \(n\)-th wind farm. \(P_{n \text{install}}^{(n)}\) is the installed capacity of the \(n\)-th wind farm. The feature of \(\sigma_{ijk}\) is shown in Fig.1.

The output power of Jiuquan wind power base is relatively low. The probability of \(\sigma_{ijk}<35\%\) is 0.966 and the probability of \(\sigma_{ijk}>55\%\) is 0. As a result, confining power output to 55% of install capacity can save transmission capacity greatly without losing power output.
2) Geographical wind power output distribution

Calculating the ratio between annual average power output of each wind farm and Jiuquan wind power base, the geographical distribution of the power output is,

\[
\alpha_{\text{gen}}^{(n)} = \frac{\sum_{i=1}^{18} \sum_{j=1}^{J} \sum_{k=1}^{24} P_{jk}^{(n)}}{\sum_{i=1}^{18} \sum_{j=1}^{J} \sum_{k=1}^{24} P_{jk}^{(n)}}, \quad n = 1, 2, \ldots, 18
\]

Where \(\alpha_{\text{gen}}^{(n)}\) is the proportion of the power output of the \(n\)-th wind farm to Jiuquan wind power base. \(J\) is the number of the days for each month.

The geographical distribution of wind power output is illustrated in Fig.2. The horizontal ordinate is the name of wind farms of Jiuquan wind power base.

B. Monthly Power Output

Monthly power output can be calculated by averaging the wind power output for a month.

\[
\sigma_{j}^{(\text{mon})} = \frac{\sum_{i=1}^{J} \sum_{j=1}^{24} \sigma_{jk}}{24J}, \quad i \in (1, 2, \ldots, 12)
\]

Where \(\sigma_{j}^{(\text{mon})}\) is the monthly power output.

Substituting (3) with (1), we can get the monthly power output of Jiuquan wind power base, as shown in Fig.3.

C. Seasonal Power Output

Seasonal power output can be calculated by averaging the wind power output for a season,

\[
\sigma_{s}^{(\text{sea})} = \frac{\sum_{i=1}^{\text{days}} \sum_{j=1}^{J} \sum_{k=1}^{24} \sigma_{jk}}{24\sum_{i=1}^{\text{days}} J_{i}}
\]

Where \(\sigma_{s}^{(\text{sea})}\) is the seasonal power output.

The seasonal power output of autumn and winter are higher than spring and summer. The relative power output of spring and summer are almost identical.

In Jiuquan, 13 wind farms are off-line all day long. The annual accumulative total number for the 13 wind farms is 227 days. Among them, HYF and LYF are outage for 87 days per year and 42 days per year respectively.

D. Daily Power Output

Due to the daily power output various with seasons, it is calculated for each season, as shown in (5).


\[
\sigma_{\text{day}}^{(x)} = \frac{\sum_{x \in \{\text{Spring, Summer, Autumn, Winter}\}} \sum_{k \in \{1, 2, \ldots, 24\}} \sigma_{ijklk} \cdot x \in \{\text{Spring, Summer, Autumn, Winter}\} \quad (5)
\]

Where \(\sigma_{\text{day}}^{(x)}\) is the relative power output at \(k\) hour in season \(x\). The result is shown in Fig.5.

Overall, the power output at dusk is more than that at midnight and morning. The daily power output in spring and autumn are similar. The largest period appears during 4 p.m. to 8 p.m. and the smallest period appears during 6 a.m. to 10 a.m. In winter, the output power is highest at 4 p.m.

### E. Wind Power Output Changing Rate

The hourly wind power output changing rate of Jiuquan wind power base is [10]:

\[
\eta_{\text{hour}} = \sigma_{ij(m+1)} - \sigma_{ijm} \quad (6)
\]

Where \(\eta_{\text{hour}}\) is the hourly changing rate for wind power output. \(\sigma_{ij(m+1)}\) and \(\sigma_{ijm}\) are the wind power output of latter hour and former hour respectively.

The calculation result of power output change rate for hour level is shown in Fig.6.

Doubly-fed induction generator (DFIG) is the common generator recent years. The stator and rotor both can produce capacitive and inductive reactive power. Sometimes, the DFIG could help us to regulate reactive power in voltage control. However, in Jiuquan wind power base, the reactive power adjustment ability of wind farms is relatively limited. Moreover, a number of wind farms drop the grid because of the failure of low voltage ride through. So the reactive compensation facility should be installed in the wind farms to avoid the voltage collapse.

### B. Effects on Voltage Stability under Various Reactive Power Compensation Modes

Different compensation modes cause different effects on voltage stability. The 35kV buses are chosen to install the reactive power compensation devices in this paper.

The boundary conditions of reactive power compensation simulation are: 1) The double mass model are used for the mechanical system of DFIG; 2) The constant voltage control mode are used for the converters; 3) The limitation range of the voltage of wind farms at the AC side buses is within 0.97~1.07p.u.; 4) the currents of the stator and converter keeps in the normal operation range.

In this paper, mainly two kinds of reactive compensation modes are discussed: Centralized configuration and Dispersed configuration. Centralized configuration mode is to install the total reactive power compensation at a single 35kV bus among the AC joint buses of BDQ, ABES, ABS, ALME and MHTY respectively. Dispersed configuration mode is to install the reactive power compensation dispersive at all the 35kV buses among the AC joint buses of five second wind farms. The SVG is utilized in this case and its capacity is 150MVar. The detailed configuration methods are shown in Tab.II.
TABLE II. THE CONFIGURATION METHODS OF CENTRALIZED AND DISPERSED REACTIVE COMPENSATION STRATEGIES

<table>
<thead>
<tr>
<th>Reactive power compensation</th>
<th>No.</th>
<th>Reactive compensation wind farm</th>
<th>Configuration method</th>
</tr>
</thead>
<tbody>
<tr>
<td>centralized compensation</td>
<td>1</td>
<td>MHTY</td>
<td>two 35kV buses, 75Mvar for each bus</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>BDQ</td>
<td>three 35kV buses, 50Mvar for each bus</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>ABES</td>
<td>four 35kV buses, 37.5Mvar for each bus</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>ABS+ALME</td>
<td>six 35kV buses, 25Mvar for each bus</td>
</tr>
<tr>
<td>dispersed compensation</td>
<td>5</td>
<td>all the second phase wind farms</td>
<td>fifteen 35kV buses totally, 10Mvar for each bus</td>
</tr>
</tbody>
</table>

Due to ABS wind farm and ALME wind farm connect to the same 330kV bus, this paper puts them together as one wind farm.

Assume a three phase short circuit fault occurs at 330kV line between Jiayuguan and Yumen, 15% away from Jiayuguan bus. The fault begins at 2.0s and lasts 200ms. Simulation results are shown in Tab.III.

TABLE III. THE VOLTAGE COMPARISON OF CENTRALIZED CONFIGURATION AND DISPERSED CONFIGURATION MODES

<table>
<thead>
<tr>
<th>Comparison groups between and dispersed compensation</th>
<th>Voltage comparison result</th>
</tr>
</thead>
<tbody>
<tr>
<td>330kV Bus Voltage magnitude</td>
<td></td>
</tr>
<tr>
<td>Yumen, Dunhuang, Bulongji, Qiaowanxin</td>
<td></td>
</tr>
</tbody>
</table>

Overall, the voltage is lower when the reactive power compensation devices are centralized configured at BDQ (No.2) or MHTY (No.1) while the voltage is higher when that centralized configured at ABES (No.3) or ABS+ALME (No.4). During normal operation mode, the steady state voltage of Yumen 330kV bus is relatively lower than Dunhuang, Qiaowanxin and Bulongji whose voltages are close to the upper limit. Therefore, the reactive power compensation should be able to enhance the voltage of Yumen as well as reduce the voltage of Dunhuang, Qiaowanxin and Bulongji appropriately.

As what we can see from Tab.III, the voltage of Yumen is relatively higher when the reactive power compensation devices are centralized configured at MHTY (No.1) than that of dispersed configuration. However, the situation at Dunhuang, Bulongji and Qiaowanxin are just the opposite. Taking Yumen and Dunhuang as an example, Fig.8 and Fig.9 show the simulation results contrast of dispersed configuration and centralized configured at MHTY.

Figure 8. Voltage comparison of Yumen 330kV bus

Figure 9. Voltage comparison of Dunhuang 330kV bus

The voltage of Yumen has obvious improvement while that of Dunhuang fell slightly after concentrated reactive power compensation adopted. The steady state voltage stays around 0.97 to 0.98 which is at the normal range and has enough margin as well.

Therefore, Centralize the reactive power compensation devices at MHTY 35kV bus can significantly improve the system voltage.

IV. CONCLUSION

The power output characteristics of Jiuquan wind power base is analyzed in detail and the effects on the voltage stability of different reactive power compensation modes are discussed in this paper. The following conclusions are drawn:

1) In autumn and winter, the power output is larger and the fluctuation of the daily power output is obvious. In addition, wind power output and the change rate are low.

2) Effective reactive power compensation should consider the voltage level of wind farm connection point. Under the premise of same compensation capacity, centralized configuration mode at the low voltage side of Yumen 35kV bus is better than other reactive compensation schemes.

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