

Feasibility Study on Equipping Energy Storage Systems in Plain Wind Farms

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Abstract

To promote the efficient development of wind energy resources in plain areas and the transformation of the energy structure, this study takes a 50MW wind power project in a certain region of Hebei Province, China, as the research object. Based on detailed feasibility study data, a systematic investigation is conducted from aspects including project site selection, wind energy resource assessment, engineering design, economic analysis, and environmental impact. The results show that the financial internal rate of return (FIRR) on the project's equity capital is 12.79%, indicating the project is financially feasible and has significant environmental benefits. This research can provide a reference for the planning and design of similar wind power projects in plain areas.

Keywords

Wind farm, wind energy resource assessment, unit selection, energy storage system, feasibility analysis.

1. Introduction

Against the backdrop of the "dual carbon" goals (carbon peaking and carbon neutrality), wind power, as one of the most technologically mature renewable energy sources with broad commercial prospects, has become a core driver for the transformation of China's energy structure. [1] The North China Plain is endowed with abundant wind energy resources and relatively concentrated land resources, providing great potential for large-scale wind power project development. Nanhe District of Xingtai City, Hebei Province, is located in the alluvial plain at the eastern foot of the Taihang Mountains, with a climate characterized as a warm-temperate semi-arid continental monsoon climate featuring distinct four seasons. Its wind energy resources exhibit obvious seasonal characteristics. [2] Drawing on the feasibility study report of the Shengli 50MW Wind Power Project in Nanhe District, Xingtai, Hebei, this paper comprehensively analyzes the feasibility of the project's development from the dimensions of wind energy resource assessment, engineering and technical design, economic benefits, and environmental benefits, aiming to provide technical support for the scientific planning of regional wind power projects. [3]

2. Overview of the Project Area and Assessment of Wind Energy Resources

2.1. Overview of the Project Area

The project is situated within the administrative boundaries of Heyang Town, Dongsanshao Township, Yanli Township, and Sansi Township in Nanhe District, Xingtai City, Hebei Province. The site features a typical alluvial plain landscape of the North China Plain, with an elevation ranging from 34.10m to 39.08m and geographical coordinates around 114°46'E and 36°55'N. The area enjoys convenient transportation, adjacent to the Donglu Expressway and G515 Expressway. The existing county and township roads within the site can serve as the basic access roads, facilitating equipment transportation and construction organization. [4]

The region has a warm-temperate semi-arid continental monsoon climate, with an average annual temperature of 13.2°C and an extreme maximum temperature of 42.5°C. The average annual precipitation is 499.6mm, with 71.2% of the total precipitation occurring in summer. The average annual sunshine duration is 2236.1h, with the most abundant sunshine in May and the least in December. Overall, the climatic conditions are conducive to the development and utilization of wind energy resources.

2.2. Assessment of Wind Energy Resources

2.2.1. Wind Measurement Data and Representativeness Analysis

The project utilizes 10-minute measured data from the 1668# wind measurement tower (located at 37°5'3.180"N, 114°44'19.320"E, with an elevation of 36m) from January 1, 2020, to December 27, 2021. The data integrity rate reaches 97.12%, which meets the requirement of "effective data integrity rate $\geq 90\%$ " specified in the Technical Specification for Wind Energy Resource Measurement and Assessment of Wind Farm Projects (NB/T31147-2018). The distance between the wind measurement tower and the farthest wind turbine site is 18km, and the distance to the nearest one is 12.8km. Although this exceeds the ideal distance requirement of 5km for wind measurement towers in plain wind farms, the topographic and geomorphic conditions of the tower site are consistent with those of the wind farm, and the elevation is basically matching that of the wind turbine sites (35-38m), ensuring good representativeness of the data.

2.2.2. Key Wind Resource Parameters

Based on the calculation using wind measurement data, the key wind resource parameters at the 160m hub height (the hub height of the wind turbines selected for the project) of the site are as follows:

Average Wind Speed and Wind Power Density: The annual average wind speed is 5.75m/s, and the average wind power density is 252.87W/m². In accordance with the NB/T31147-2018 standard, the wind power density is classified as Grade D-2, indicating commercial development value.

Wind Direction and Wind Energy Distribution: The dominant wind direction is south (S) with a frequency of 18.01%, and the main wind energy direction is also south (S) with a frequency of 29.50%. There are significant seasonal differences in wind speed and wind power density: the wind speed is relatively high from February to May (with an average of 6.5-7.39m/s) and relatively low from August to September (with an average of 4.64-4.84m/s). The diurnal variation pattern shows that at heights of 120m and above, the wind speed tends to "decrease first and then increase", reaching the minimum from 8:00 to 10:00 and the maximum from 20:00 to 23:00; at heights below 50m, the wind speed shows a trend of "increasing first and then decreasing", with the minimum from 0:00 to 8:00 and the maximum from 12:00 to 15:00.

Turbulence Intensity and Wind Shear Exponent: In accordance with the IEC61400-1 (2019 edition) standard, the turbulence intensity of the site is classified as Grade B. The average wind shear exponent at heights of 30-120m is 0.368, indicating that the wind speed increases significantly with height. The adoption of a 160m high tower can effectively improve power generation.

Extreme Wind Speed: The 50-year return period maximum wind speed is 32.79m/s. In line with IEC standards, wind turbines of safety class III B are selected to ensure safe operation under extreme weather conditions.

3. Engineering Design Scheme

3.1. Selection and Layout of Wind Turbines

3.1.1. Turbine Selection

Considering the scarcity of land resources at the site, equipment technical maturity, and economic efficiency, the project compares four mainstream turbine models (5.0MW, 5.27MW, 5.6MW, and 6.25MW) and ultimately selects 8 wind turbines with a single-unit capacity of 6.25MW (model WTG4). The specific parameters are shown in Table 1:

Table 1. The specific parameters of wind farms

Parameter	Index
Rated Power	6250kW
Rotor Diameter	220m
Hub Height	160m
Cut-in Wind Speed	2.5m/s
Rated Wind Speed	8.7m/s
Cut-out Wind Speed	20m/s
Survival Wind Speed	59.5m/s
Generator Rated Voltage	1140V

This turbine model has a swept area of 38,013m², which is 21% larger than that of the 5.0MW model, enabling more efficient capture of wind energy. Additionally, it features a low cut-in wind speed (2.5m/s) and a moderate rated wind speed (8.7m/s), which are well-suited to the wind resource characteristics of the site. The theoretical annual power generation per unit reaches 20.0925 million kWh.

3.1.2. Turbine Layout

Adhering to the principles of "making full use of wind energy, reducing wake losses, and saving land" and considering the characteristics of the dominant wind direction (S), the spacing between wind turbines along the dominant wind direction is no less than 5 times the rotor diameter (1100m), and the spacing perpendicular to the dominant wind direction is no less than 2.5 times the rotor diameter (550m). After optimizing the layout using WT software, the 8 wind turbines are placed at positions F8, F9, and F11-F16, with a total installed capacity of 50MW. The wake loss is controlled within 4.8%, and the wind energy utilization efficiency is improved by 3%-5% compared with conventional layouts.

3.2. Design of Energy Storage System

To enhance the consumption capacity of new energy power and grid stability, the project is equipped with a 10MW/40MWh lithium iron phosphate battery energy storage system. It adopts a modular configuration of "2×5MWh battery containers + 2.5MW converter-booster integrated units", with a total of 4 energy storage units. The energy storage system is connected

to the 35kV side bus of the 220kV booster station via one 35kV cable, and has the following functions:

Peak Shaving and Valley Filling: Smoothing the fluctuation of wind power output, storing electricity during low-load periods, and discharging during peak-load periods to improve the stability of power supply.

Auxiliary Services: Participating in grid frequency regulation, with a response time of $\leq 200\text{ms}$ and a regulation accuracy of $\pm 2\%$.

Backup Power Supply: Serving as an emergency power source in case of grid failures to ensure power supply for key equipment.

The energy storage battery containers have an IP55 protection rating, with a built-in automatic fire alarm system and a heptafluoropropane fire-extinguishing device, meeting the operational requirements in harsh outdoor environments. The Battery Management System (BMS) adopts a three-level architecture (BMU-CMU-BSC), which can real-time monitor the cell voltage, temperature, and State of Charge (SOC) to ensure the safe operation of the system.

3.3. Design of Electrical and Civil Engineering

3.3.1. Electrical System

Grid Connection System: The wind farm is connected to the 35kV side bus of the Shengling 50MW Wind Power Project 220kV Booster Station in Nanhe District via two 35kV collector lines. The collector lines adopt a hybrid laying method of "overhead lines + cables". The total length of overhead lines is 19.6km (5.6km for single-circuit lines and 14km for double-circuit lines), using JL/G1A-120/25 and JL/G1A-185/30 steel-cored aluminum stranded wires. The total length of cable lines is 6km, using ZC-YJY23-26/35kV series copper-core cables. For sections crossing expressways and railways, $3 \times 300\text{mm}^2$ cables are used to ensure power supply reliability.

Control and Protection: A wind power prediction system (0-72h short-term prediction, 15min-4h ultra-short-term prediction), an Active Power Control (AGC) system, and an Automatic Voltage Control (AVC) system are configured to meet the requirements of grid dispatching. The wind turbines and box-type transformers adopt a triple protection mechanism of "overcurrent protection, overvoltage protection, and temperature protection" to ensure the safety of equipment.

3.3.2. Civil Engineering

Wind Turbine Foundation: Pile-supported cap foundations are adopted, with concrete of strength grade C40 (frost resistance grade F150, impermeability grade P6). The cap has a diameter of 21.8m and a total height of 4.6m. Under the cap, there are 43 bored piles with a diameter of 800mm and a length of 32m (using C35 concrete). The pile foundation's bearing stratum is selected as the ⑦ layer fine sand, with a characteristic value of bearing capacity of 280kPa, which meets the vertical and horizontal load requirements of the wind turbines.

On-site Roads: A total of 24.2km of new roads and 13.8km of expanded roads are constructed. The road width is 5m during the construction period and 4m during the operation and maintenance period. The road structure adopts "20cm muddy gravel surface layer + 3cm gravel wearing layer". The turning radius is $\geq 50\text{m}$ to meet the transportation needs of wind turbine equipment and operation and maintenance vehicles. A passing lane is set every 500m to ensure smooth traffic.

4. Analysis of Economic and Environmental Benefits

4.1. Investment and Benefits

Investment Composition: The static investment of the project is 308.0396 million yuan, and the dynamic total investment is 312.4754 million yuan. Among the total investment, equipment purchase cost accounts for 149.1444 million yuan (47.7%), construction engineering cost accounts for 43.7097 million yuan (14.0%), installation engineering cost accounts for 41.6747 million yuan (13.3%), and other expenses account for 47.1374 million yuan (15.1%).

Benefit Indicators: Calculated based on an average on-grid electricity price of 0.33 yuan/kWh (including value-added tax), the project's annual sales revenue is 36.8235 million yuan. The return on investment is 4.79%, the return on equity capital is 14.08%, the financial internal rate of return (FIRR) on project investment (after tax) is 6.96%, and the investment payback period (after tax) is 11.45 years, which is better than the industry average level (the average payback period of wind power projects is 12-15 years).

4.2. Environmental Benefits

Compared with thermal power units with the same power generation capacity (coal consumption of 301.6g/kWh), the project can save 33,654.49 tons of standard coal annually and reduce pollutant emissions, including 9.26 tons of sulfur dioxide (SO₂), 14.84 tons of nitrogen oxides (NO_x), and 1.90 tons of soot. Meanwhile, it can reduce greenhouse gas carbon dioxide (CO₂) emissions by 91,947.28 tons, which is equivalent to planting approximately 250,000 trees, demonstrating significant environmental benefits. In addition, during the construction period, measures such as "sprinkling water to reduce dust, balancing earthwork, and restoring vegetation" are adopted, and there is no wastewater or waste residue discharge during the operation period, ensuring that the impact on the regional ecological environment is controllable.

5. Conclusion and Recommendations

5.1. Conclusion

The site of the Shengling 50MW Wind Power Project in Nanhe District, Xingtai, Hebei, is rich in wind energy resources. At a hub height of 160m, the annual average wind speed is 5.75m/s and the wind power density is 252.87W/m², providing favorable conditions for development.

The engineering design scheme is reasonable. The configuration of 6.25MW wind turbines combined with a 10MW/40MWh energy storage system achieves an annual on-grid electricity volume of 111.5865 million kWh, demonstrating good technical and economic performance.

The project is financially feasible and has significant environmental benefits. It can effectively promote the transformation of the regional energy structure and conform to the requirements of the national "dual carbon" goals.

5.2. Recommendations

In the next stage, it is necessary to further supplement the wind measurement tower data within the site, recheck the wind resource characteristics, and optimize the layout of wind turbine sites.

During the construction period, emphasis should be placed on foundation pit support and wind turbine hoisting safety, and special plans should be formulated to deal with extreme weather.

During the operation period, strengthen the operation and maintenance management of wind turbines and energy storage systems, improve the equipment availability rate (with a target of ≥95%), and ensure the long-term stable benefits of the project.

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