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Control Strategy and Economic Benefit Analysis of Wind Turbine Blade Replacement

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Abstract: This paper takes a 1.5 MW wind turbine wind farm in Jilin province as an example. It analyzes the improvement of blade lengthening in wind turbine power generation by optimizing control strategy and adopting intelligent control technology. And it compares the economic benefits of replacing 82 blades and 89 blades and provides a theoretical and practical basis for blade lengthening transformation of other wind farms.

1. Introduction

China's wind energy industry has developed steadily and orderly in recent years, with an installed capacity of 300 million kilowatts and more than 170000 wind turbines connected to the grid. The total installed capacity ranks first globally [1-3]. Currently, the total installed capacity of a single unit of 1.5 MW in China is nearly 80 million kilowatts, and the number of units exceeds 5000 [4-5]. Due to these units' early development, most are in areas with rich wind resources. However, due to the limitations of technical conditions at the early stage of wind power industry development, wind farms generally have problems such as feasibility studies, micro-siting, and load assessments that are relatively rough. In addition, few models were available then, and there was a deviation in unit selection. To some extent, it causes a waste of wind resources [6-8].

In response to such problems, the National Energy Administration proposed in the "Fourteenth Five Year Plan" for Renewable Energy Development that renewable energy should achieve a high-quality leap forward development during the "Fourteenth Five Year Plan" period. And it further improves the quality and efficiency and promotes the sound and recyclable development of the wind power industry. It aims to actively respond to the work call of the national energy management department and further alleviate the operating pressure caused by the gradual decline of wind power grid price and the continuous high operation and maintenance costs. This paper analyzes the feasibility of blade lengthening for a 1.5 MW unit in a wind farm to improve power generation efficiency.

2. Blade lengthening technical scheme

2.1 Theoretical basis of the scheme

By replacing long blades, the wind-catching area of the original wind turbine and the unit's power in the low wind speed period are increased, thus increasing the annual power generation of the unit [9-11]. Compared with other ways of increasing power, such as lengthening the blade tip and installing a vortex generator, the power increase effect of replacing long blades is more significant. It is easy to conduct safety assessments and control strategy adjustments [12, 13].

$$P = \frac{1}{2}\rho V^3 A C_P \quad (1)$$

According to the calculation Formula (1) of wind turbine power generation, for a specific wind farm, its air density, wind speed, and other environmental factors cannot be changed. When designing the blade replacement technical transformation scheme, it is necessary to carry out customized design according to the actual wind resources of the wind farm and the overall health status of the unit to achieve the purpose of power increase on the premise of ensuring the safety of the unit [14-16].

2.2 Control strategy optimization

After the blade is replaced with a long blade, the impeller diameter and blade characteristics have changed, and the optimal pitch angle and the OptGain coefficient of the optimal torque control must be recalculated. At the same time, according to the adjusted Bladed fan model and the tuning principle of the new unit controller, the controller parameters of torque PI and pitch PI are tuned and adjusted, and the controller dll is generated for load calculation. Based on the calculation results, the

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parameters of the control part are re-optimized. After several rounds of iterative control parameter tuning and load calculation evaluation, the iterative results meet the design requirements.

On the premise of ensuring the systematic safety of unit control, according to the comprehensive survey information of the wind farm, the optimization scheme of the main control program is determined, and the corresponding intelligent control module is selected to achieve the intelligent control of one unit and one project. The unit has the function of online identification of wind direction deviation, which ensures that the unit can accurately and timely wind, absorb more wind energy and improve the generating capacity of the unit. We ensure that the generating capacity of the unit in the low wind speed area is increased by more than 5% on average. After full power generation, the generating capacity of the unit is increased by 2.7% on average, and the annual generating capacity can be increased by 3%~5%.

2.2.1 Intelligent pitch control technology

The intelligent pitch control technology is applied to low wind speed (wind speed is less than 10 m/s) to dynamically find the optimal value of blade pitch angle at low wind speed to ensure that the unit operates on the optimal Cp curve. In the low wind speed range, it is necessary to optimize the algorithm for finding the minimum pitch to improve the power generation of the fan. The pitch angle needs to change with the change in wind speed to ensure that the fan operates on the curve with the highest wind energy utilization coefficient to improve power generation. The curve of wind energy utilization coefficient changing with wind speed is shown in Figure 1. At low wind speeds, the blade angle needs to be adjusted according to the change in wind speed. Generally, the blade will complete the change of the minimum angle value within the range of wind speed from 4 m/s to 4.5 m/s (1150-1200 rpm), while the blade angle in the original control range from 4 m/s to 6 m/s is unchanged, with slow response and low efficiency. In the high wind speed range (10-11.5 m/s), after the fan speed reaches the rated speed, we adjust the pitch angle to ensure that the unit operates on the best CP curve to improve power generation. After iterative calculation of the simulation model using an intelligent pitch control strategy, the wind speed CP curve is shown in Figure 2. Obviously, the CP value in the low wind speed area has been significantly improved, and the simulated power generation has increased by 3% - 4% compared with the measured data.

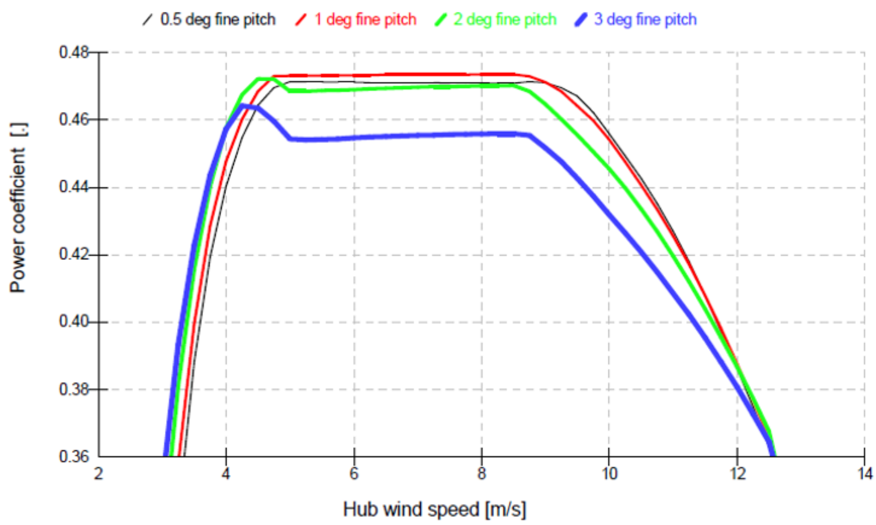

Figure 1 Wind energy utilization coefficient Cp corresponding to different pitch angles at different wind speeds

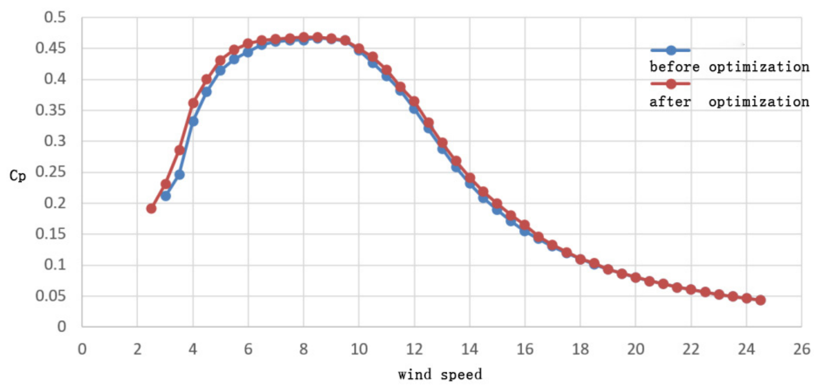

Figure 2 Cp under each wind speed after adopting an intelligent pitch control strategy

2.2.2 Intelligent wind direction deviation correction technology

The wind direction deviation mainly comes from the installation error and system error. The negligence of the on-site installation personnel usually causes installation errors. The system error is usually caused by the influence of the blade wake, as shown in Figure 3.

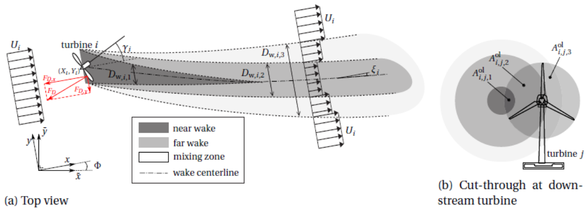

Figure 3 Wake interference model of wind turbine

In addition to the above main factors and various installation technologies and environmental interference factors, the actual wind strategy of the unit may have a certain degree of deviation. That is, the 0° deviation position of the unit is not the optimal wind angle. The unit data analysis before the wind error correction is shown in Figure 4. The centerline of the data scatter points does not fall near 0° as designed but has a deviation of about -10°. It means that the -10° position of the unit is the position where the unit can obtain the maximum wind energy at this time. Therefore, the parameters can be adjusted according to the actual operation of each unit in the wind farm.

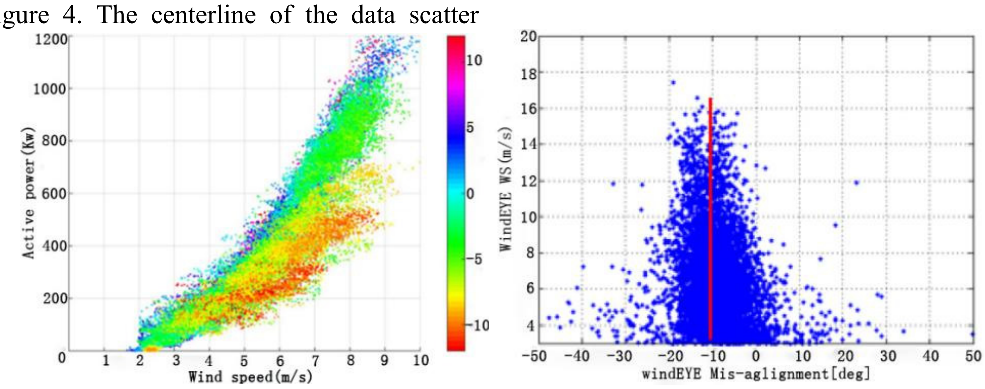

Figure 4 Unit data analysis before wind error correction

The data analysis results of the adjusted unit are shown in Figure 5. The wind direction deviation correction technology is based on comparing many operating data of the fan and modeling multiple subsystems of the unit to achieve the function of multivariable optimization and wind direction deviation identification. The deviation of the wind direction of each unit is obtained, and the operating parameters of each unit are optimized in the software to eliminate the wind direction deviation and ensure the unit's accuracy in the wind direction. Thus, the generating capacity of the unit and the power curve of the unit can be improved, and the generating capacity can be increased by 1% - 1.5% by eliminating the angle deviation of the wind.

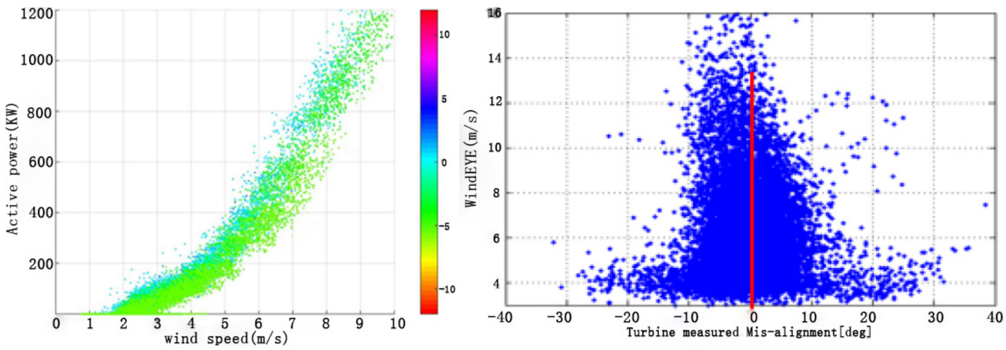

Figure 5 Unit data analysis after wind error correction

2.2.3 No-load idling control technology

The no-load idling control technology is applied to pitch the unit in advance when the wind speed is close to the starting wind speed when the unit starts up. The unit is disconnected from the grid but not feathered under low wind conditions (idling operation for a period of time) to ensure that the unit is idling at a certain angle and speed up the rapid grid connection of the unit when the next wind conditions are met. After the optimization of no-load idling control, as shown in Figure 6, the grid can be connected for power generation 30 minutes in advance.

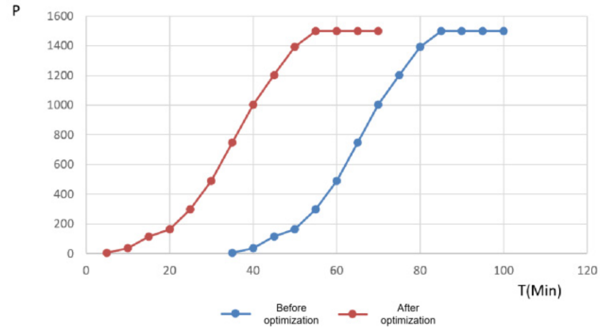

Figure 6 Power change curve before and after no-load idling control

2.2.4 Intelligent high wind cut-in and cut-out control technology

The key components of the unit, such as the generator, frequency converter, gearbox, blade, and other equipment information, dynamically adjust the parameters and logic of the unit, such as high wind cut out, soft cut out, and re-cut in. On the premise of ensuring the unit's safety, when the instantaneous wind speed reaches the cut-out wind speed condition, the unit high wind speed optimization scheme is adopted. The cut-out wind speed is changed from 25 m/s direct cut-out to 28 m/s slow cut-out operation. It is conducive to improving the generating capacity of the unit under high wind speed.

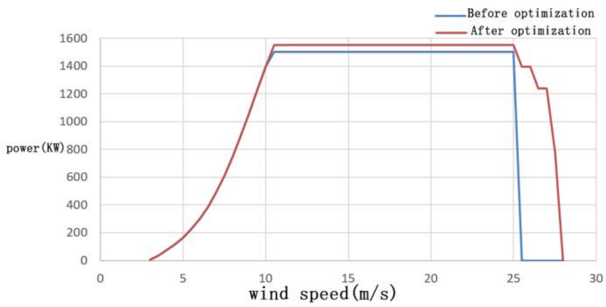

Figure 7 Comparison before and after high wind speed optimization scheme

2.3 Calculation of power generation increase

According to the actual situation of a wind farm, the power curve will be significantly improved after the 82 blades of the unit are replaced, as shown in Figure 8.

2.3.1 Power generation increase of 77 for 82 blades in a wind farm

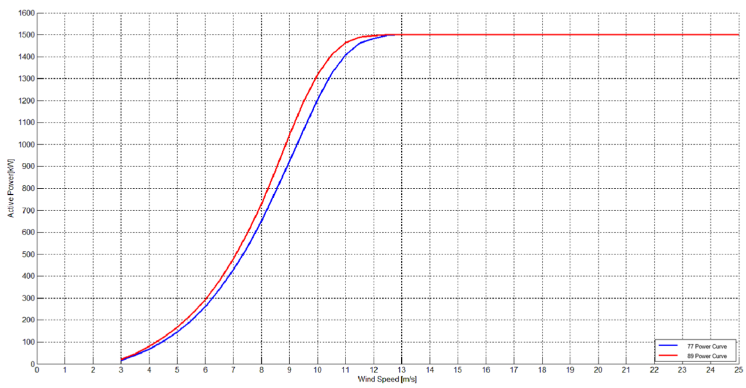

Figure 8 Power curve comparison of a wind farm unit after 77 blades were replaced with 82 blades

By integrating the above power curve with the annual wind speed distribution curve of the wind farm (Weibull wind speed distribution model with k=2), each unit's annual theoretical power generation (AEP) before and after the technical transformation can be calculated. Table 1 shows the theoretical power generation increase of the wind farm under different annual average wind speeds. Considering the micro-location of each unit, the comprehensive annual average wind speed of a wind farm is 6.5 m/s. After the technical transformation of 77 for 82 blades, Power generation can be increased by 9.79%.

Table 1 Comparison of annual power generation (theoretical value) of units before and after blade replacement (77 for 82)

No.	Average wind speed [m/s]	Annual theoretical full-service hours [h]		The proportion of power generation increase (%)
		Before technical transformation	After technical transformation	
1	4.00	515	607	17.89%
2	4.50	740	858	16.01%
3	5.00	999	1141	14.23%
4	5.50	1281	1442	12.58%
5	6.00	1574	1749	11.10%
6	**6.50**	**1869**	**2052**	**9.79%**
7	7.00	2158	2344	8.65%
8	7.50	2435	2621	7.67%
9	8.00	2695	2879	6.82%
10	8.50	2938	3116	6.09%
11	9.00	3159	3332	5.46%

2.3.2 Power generation increase of a wind farm by replacing 77 blades with 89 blades

According to the actual situation of a wind farm, after replacing 89 blades, the power curve of the unit is improved, as shown in Figure 9.

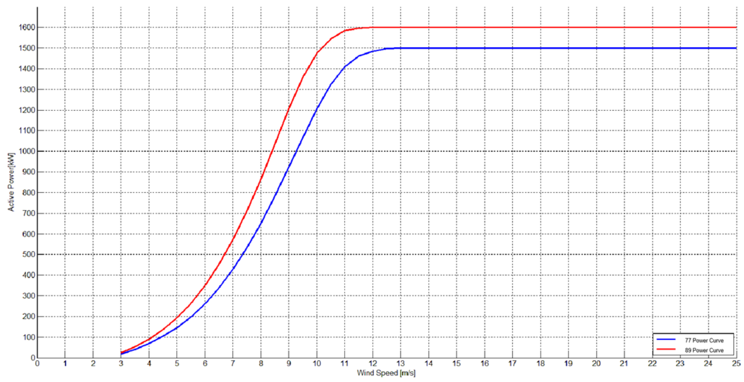

Figure 9 Power curve comparison of a wind farm unit after 77 blades were replaced with 89 blades

By integrating the above power curve with the annual wind speed distribution curve of the wind farm (Weibull wind speed distribution model with k=2), each unit's annual theoretical power generation (AEP) before and after the technical transformation can be calculated. Table 2 shows the theoretical power generation increase of the wind farm under different annual average wind speeds. Considering the micro-location of each unit, the comprehensive annual average wind speed of a wind farm is 6.5 m/s. After the technical transformation of 77 for 89 blades, power generation will increase by 19.41%.

Table 2 Comparison of annual power generation (theoretical value) of units before and after blade replacement (77 for 89)

No.	Average wind speed [m/s]	Annual theoretical full-service hours [h]		The proportion of power generation increase (%)
		Before technical transformation	After technical transformation	
1	4.00	515	701	36.17%
2	4.50	740	982	32.79%
3	5.00	999	1290	29.15%
4	5.50	1281	1608	25.60%
5	6.00	1574	1925	22.32%
6	**6.50**	**1869**	**2232**	**19.41%**
7	7.00	2158	2522	16.86%
8	7.50	2435	2791	14.65%
9	8.00	2695	3039	12.76%
10	8.50	2938	3264	11.12%
11	9.00	3159	3467	9.72%

2.4 Economic benefit analysis

After blade replacement, if there is no power limitation and the annual average wind speed of the wind farm is 6.5 m/s, the income and capital recovery period of blade replacement 82 and 89 are shown in Table 3. The investment cost of blade replacement 89 is higher than that of blade replacement 82. Still, the cumulative income in the remaining six years of the life cycle is higher, and the capital recovery period is shorter, so the economy of blade replacement 89 is higher.

Table 3 Income statement of technical transformation of replacing long blades in a wind farm (average single unit)

No.	Item	Replace 82 blades	Replace 89 blades
1	Average wind speed (m/s)	6.50	6.50
2	Utilization hours before technical transformation (h)	2200	2200
3	Technical improvement range (%)	9.79%	19.41%
4	Annual improved utilization hours (h)	215.38	427.02
5	Production time	2008.8	2008.8
6	Remaining life cycle (year)	6	6
7	Electricity price (yuan/kWh)	0.63	0.63
8	Annual income added value (10000 yuan/unit)	20.35	40.35
9	Technical transformation cos t (10000 yuan/unit)	100	185
10	Capital payback period (year)	4.91	4.58

3. Conclusion

With the continuous development of wind power generation technology, the utilization rate of wind resources has been greatly improved compared with that before. It is necessary to upgrade the old wind farm. In this paper, for the 1.5 MW unit in a wind farm in Jilin, the power generation is increased by replacing the long blades. After replacing the blades, the unit's control strategy is optimized, and the power generation is calculated. The calculation shows that power generation can be increased by 19.41% after replacing the blades. The cost can be recovered during the service period. This paper mainly discusses the feasibility of blade lengthening from the actual point of view, which provides a theoretical and practical basis for similar technical innovations of other wind farms.

References

[1] Song, J.B. (2022) Summary of situation and development of wind power generation technology. APPLICATION OF IC, 39(04):148-149.

[2] Wang, Q. (2021) Forecast of Chin's wind power installed capacity and corresponding CO_2 reduction from 2020 to 2060, 37(07):13-21.

[3] Xia, Y.F. (2022) 93.6GW of new wind power installed capacity in the world in 2021. Wind Energy, 06:38-43.

[4] An, Z.W., Yang, X.X., Kou, H.X., Gao, J.X., (2020) Multi-axial fatigue life analysis of 1.5MW wind turbine blades. Acta Energiae Solaris Sinica, 41(05):129-135.

[5] Xiao, J.P., Chen, L., Xu, B.F., Wu, J., (2011) Investigation on aerodynamic performance of a 1.5MW wind turbine. Acta Aerodynamica Sinica, 29(04):529-534.

[6] Gallas, H., Ballois, S.L., Aloui, H., Vido, L., (2020) Robust Control and Harmonics Modeling of a PMSG for a 1.5 MW Wind Turbine, In: 2020 International Conference on Electrical Machines (ICEM). Gothenburg. pp. 305-311.

[7] Rydh, C.J., Jonsson, M., Lindahl, P., (2004) Replacement of old wind turbines assessed from energy. Environmental and economic perspectives, 38:1-26

[8] Simons, P.J., Cheung, W.M., (2016) Development of a quantitative analysis system for greener and economically sustainable wind farms. Journal of Cleaner Production, 133:886–898.

[9] Ma, P., (2008) Validation on the power curve of wind power unit. Renewable Energy Resources, 26(06):82-84.

[10] Lion, H., Simon, M., (2016) System-friendly wind power: How advanced wind turbine design can increase the economic value of electricity generated through wind power. Energy Economics, 56:51-63.

[11] Hyungyu, K., Kwansu, K., Insu, P., (2016) Power regulation of upstream wind turbines for power increase in a wind farm. International Journal of Precision Engineering and Manufacturing, 17:665-670

[12] Huang, Y.H., Yang, R.Z., (2019) Analysis and research on extended wind turbine blades. Tianjin Science & Technology, 46(07):36-37+42.

[13] Wang, H.M., Zeng, X.G., (2021) Feasibility of blade lengthening technical transformation of a wind turbine unit in service and analysis of AEP lifting effect. Wind Energy, 06:72-75.

[14] Zhang, J., Jiang, N., Li, H., Li, N., (2019) Online health assessment of wind turbine based on operational condition recognition. Transactions of the Institute of Measurement and Control, 41(10):2970-2981.

https://doi.org/10.1051/e3sconf/202337002003

[15] Bilmes, J.A., (1998) A gentle tutorial of the EM algorithm and its application to parameter estimation for Gaussian mixture and hidden Markov models. International Computer Science Institute, 4(510):1-13.

[16] Ren, Y., Wu Q.R., Xue, L.M., (2014) Health assessment of wind turbine. Advances in New and Renewable Energy, 2(06):430-433.