Journal of Power and Energy Engineering, 2014, 2, 288-296
Published Online April 2014 in SciRes. http://www.scirp.org/journal/jpee
http://dx.doi.org/10.4236/jpee.2014.24040

Scientific Research

Post Evaluation of Wind Resource Assessment and Micro-Siting

Shuang Han[1*], Linyue Gao[1], Yongqian Liu[1], Wei Yang[2]

[1]State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing, China
[2]North China Power Engineering Co., Ltd. of China Power Engineering Consulting Group, Xicheng District, Beijing, China
Email: *hanshuang1008@sina.com, linyue816@hotmail.com

Received February 2014

Abstract

The design energy productions deviate from the actual situation, which are affected by the accuracy of two significant factors - the wind resource assessment and wind farm micro-siting. A running wind farm in northern China was taken as the object in this investigation. The measured data obtained in operation phase and the relevant information in design phase were integrated and a post evaluation of wind resource assessment, micro-siting and generating capacity reduction factors of the wind farm in design phase was provided. The results indicate that the representative year wind regimes of the wind farm in design phase can basically reflect the wind conditions in the wind farm without the consideration of the trends of long-term changes in wind speed; micro-siting project in design phase is superior to that in practical; generating capacity reduction factors, overall on the high side, should be further optimized considering 20-year operation period.

Keywords

Post Evaluation; Wind Resource Assessment; Micro Siting; Reduction Factor

1. Introduction

Wind power has entered the scale-development stage, but there are still some problems and obstacles. One of them is the design generating capacity of a wind farm vary greatly from the practical one. The investor's profits and strategic decision are affected by the deviation, no matter it is positive or negative. The project post evaluation work can be performed through the analysis and evaluation of the implemented part, which will improve the subsequent decision-making and implementation of the project. With an increasing number of wind farms, the post evaluation of wind farms is more significant than ever, and some scholars have conducted researches [1-4]. The above studies are mainly focused on the general methods of post evaluation, the project's overall economic post-evaluation studies and relevant fields. Post-evaluation investigations for the wind resource assessment and micro-siting of wind farms are comparatively rare.

[*]Corresponding author.

How to cite this paper: Han, S., Gao, L.Y., Liu, Y.Q. and Yang, W. (2014) Post Evaluation of Wind Resource Assessment and Micro-Siting. *Journal of Power and Energy Engineering*, **2**, 288-296. http://dx.doi.org/10.4236/jpee.2014.24040

The object of the study is a certain wind farm in northern China, which has been put into practical operation. In this work, the measured data of the operational phase were compared with the index of design phase [5,6]. The differences between them and the reasons for these differences were uncovered to improve and optimize the wind farm design.

2. Research Object

A wind farm in the northern China was chosen as the research object. Wind meters were installed at the height of 10 m, 55 m, 65 m and 80 m of the anemometer towers respectively during the process of wind measurement. This wind farm shows great development value as well as abundant wind resources with the annual average wind speeds of 7.1 m/, 8.7 m/s, 8.9 m/s and 9.1 m/s. The average power densities are 364 W/m^2, 674 W/m^2, 716 W/m^2 and 772 W/m^2, annual average wind power density in Class 6 for many years [7].

The feasibility research of this wind farm was completed in April, 2005, twenty WTG1500D wind turbines were recommended in the feasibility study and corresponding calculation of energy production had been conducted. But for various reasons, 36 WTG850C wind turbines were practically constructed by the owners, which was inconsistent with the feasibility report.

The data of anemometer towers in the feasibility report were collected from the 1# anemometer tower. In fact, all measurements were gathered from new l# and new 2# tower because the l# tower had been dismantled. After testing, a serious lack of the measurements, which didn't meet the standard of effective data rate of 90%, led to useless data from new l# tower. New 2# tower has complete data records, but wind measurement data are relatively lower at 70m and 60m due to the equipment failure. Therefore, the data obtained at 50 m of new 2# tower was adopted in the following post evaluation in this investigation.

To post-evaluate design indicators of this wind farm, the actual operation data from October 1, 2008 to September 30, 2009 were selected to be compared with the relevant data and indicators designed before.

3. Data Collection

In order to conduct post evaluation more accurately, details in design phase as well as operational phase are needed. The data collection included the wind farm work logs during operational phase, statistical reports of the energy production during operational phase, data from wind monitoring system, the availabilities of wind turbines, failure registration forms, wind measurement data both in design phase and operational phase, the feasibility research report of the wind farm, the topographic maps and relevant data of wind turbines.

4. Content of Evaluation

Evaluation mainly consists of the post evaluation of wind resources and the post evaluation of energy production.

The post evaluation of wind resources investigated through the comparison between the measured wind regime in operational phase and the revised data of wind regime during the feasibility study stage to verify the accuracy and reasonableness of wind resource evaluation, including annual and monthly wind conditions. The annual wind conditions chiefly contain the contrast of the annual average wind speed, the contrast of the curves of the diurnal variations of wind speed all year round, the contrast of the curves of the diurnal variations of wind energy all the year round, the contrast of the curves of annual variations of wind speed, the contrast of the curves of annual variations of wind energy, the contrast of the wind speed and wind power frequency distribution histograms all year round, the contrast of the wind direction roses all year round and the contrast of the wind energy roses all year round. Evaluation on monthly wind conditions is similar with the annual one.

The post evaluation of energy production mainly compared the actual power generation capacity in operational phase and the estimated power generation capacity in design phase and revealed the significant reasons for variations. This work is focused on the investigation of rationality in reduction factors adopted in estimation.

5. Assessment Case Study

According to national standard GB/T18710-2002, data in two phases were processed, and a variety of wind conditions parameters worked were graphed [7-10]. In this way, changes in wind speed, wind direction and wind energy can be discussed more visually, and it is more conducive to compare the trend of the parameters before and after.

5.1. Wind Resource Post Evaluation

Post evaluation is mainly based on annual wind conditions.

1) Annual average wind speed

The annual wind speeds of design phase and operational phase are 8.70 m/s and 8.32 m/s, and wind speed in operational phase is 4.37% lower than that in design phase.

2) Comparison of wind speed diurnal variation curve of a year

After screening and averaging wind speeds in a certain period of time in a whole year using Equation (1), 24-hour diurnal variation laws were obtained.

$$V_i = \frac{1}{n}\sum_{j=1}^{n} v_{ij} \tag{1}$$

In Equation (1): V_i is the average wind speed at i^{th} period of everyday in a whole year (m/s, $i = 0 - 23$); n is the number of wind speeds at i period of everyday in a whole year (365 in common); v_{ij} is the j^{th} of all wind speeds in i^{th} period in a whole year, m/s.

Figure 1 shows a comparison of wind speed diurnal variation curves between design phase and operational phase.

The maximum deviation, the minimum deviation and the average deviation of annual wind speed diurnal variations curves in design phase and operational phase respectively are 10.30%, 0.32%, and 4.47%.

As can be seen in **Figure 1**, the annual wind speed diurnal variations curves are consistent with each other in two phases, but the actual wind speed is slightly lower than that in design phase, mainly between 4:00 am and 16:00 pm of a day. The annual average wind speeds in operational phase are lower than those in design phase.

Wind power density curves are similar to the wind speed curves above, no narrative further.

3) Comparison between annual wind speed variation curves

Figure 2 shows a comparison chart of annual wind speed variation curves in design phase and operational phase, which depends on statistics calculation results.

From **Figure 2**, the regulation pattern in annual variations of wind speed in operation phase is similar to that in design phase. The maximum relative deviation, the minimum relative deviation and the average relative deviation respectively are 28.65%, 5.95% and 13.93%. The larger deviations occur in January (27.81%), February (22.35%) and June (28.65%). Because the wind energy production data in the same period of wind speed data are available, wind regime variation tendency could be confirmed by the trends behind changes of energy production.

4) Annual frequency distribution of wind speed and Wind energy

The frequency distribution of wind speed and wind energy throughout the year is based on a wind speed interval of 1m/s. The occurrence frequencies of wind speed and wind energy in an individual wind speed interval were counted and the number of each wind speed section represents the median.

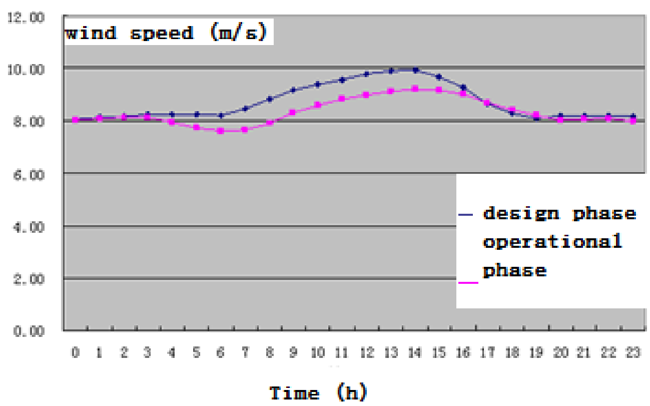

Figure 1. Annual wind speed diurnal variation curves.

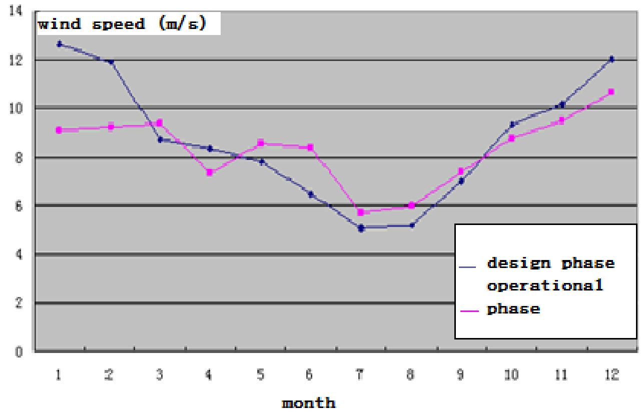

Figure 2. Annual wind speed diurnal variation curves.

To calculate wind energy frequency, the wind energy density within each wind speed segment (*i.e.*, a unit of wind energy) is required depending on Equation (2).

$$D_i = \frac{1}{2}\sum_{j=1}^{m}(\rho)(v_{ij}^3)t_{ij} \tag{2}$$

In Equation (2): D_i is the i^{th} interval of wind energy density (W·h)/m^2; m represents the number of wind speed intervals; ρ is air density (kg/m^3) ; v_{ij} is the j^{th} wind speed (m/s) cubic values in the i^{th} wind speed interval; t_{ij} is the Occurrence time of the j^{th} wind speed in the i^{th} wind speed interval within a certain sector or all sectors (h).

Wind energy frequency in one wind speed interval was obtained by dividing wind energy densities in an individual wind speed interval obtained from the Equation (2) by the sum of them (the total wind energy density).

Figures 3 and **4** are respective comparison of the annual frequency distribution of wind speed and wind energy in design phase and operational phase.

Frequency distributions of the two phases are similar, indicating that the revised wind regimes in the representative year in design phase corresponding to the actual conditions.

5) Comparison between two phases of annual wind direction roses and wind energy roses

The hourly data in design phase and operational phase were drawn into two-stage annual wind direction rose diagrams, as shown in **Figure 5**.

Wind directions during design phase and operational phase are relatively concentrated. The predominant wind directions in design phase and operational phase respectively are NW (21.2%) and WNW (23.9%).

According to the hourly observation data of wind speed and wind direction, statistical calculation of wind energy in each sector was conducted, and wind energy frequency were obtained by dividing the wind energy in individual sector with the total wind energy. Wind energy in each sector was calculated by Equation (2), but the meaning of i in Equation (2) changed into i^{th} sector. Wind energy frequency in each sector is the wind energy in this sector divided by the total wind energy.

The wind energy roses were drawn according to the wind energy frequency in each sector. The annual wind energy rose diagrams in design phase and operational phase were shown in **Figure 6**.

Wind energy are concentrated in design phase as well as in operational phase, consistent with wind direction respectively, NW (36.6%) and WNW (33.7%). The dominant wind direction, northwest, is consistent in two phases. The dominant wind direction in operational phase indicates a south deviation compared with that in design phase.

Comparison of wind regime monthly equals to compare the monthly wind speed and wind power density diurnal variation curves, and monthly wind direction roses and wind energy roses. Overall, the design phase of diurnal variation curves of wind speed and wind power density of each month are representative to describe diurnal variations of wind speed and wind power density in each month.

5.2. Post Evaluation of Energy Production Estimation

In order to compare the wind regime between design phase and operation phase of the wind farm, WAsP was

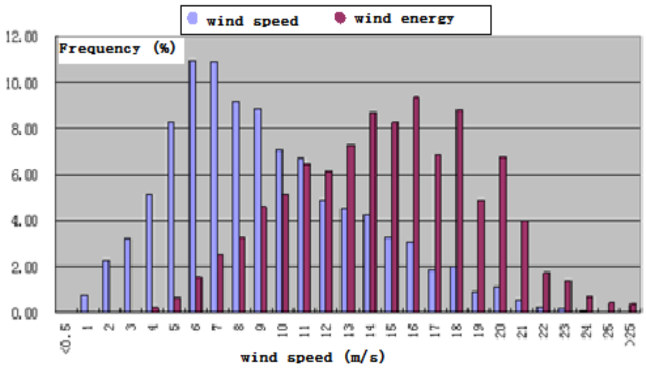

Figure 3. Annual wind speed and wind energy frequency distribution histograms in design stage.

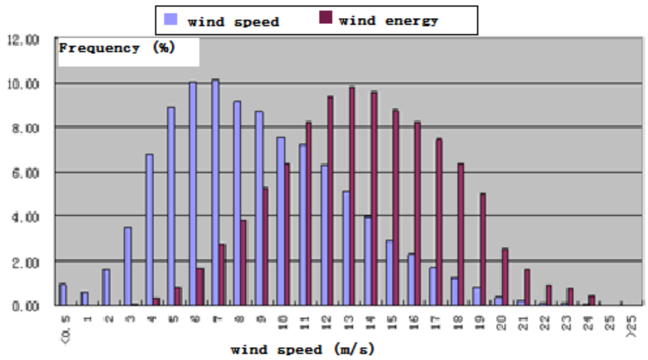

Figure 4. Annual wind speed and wind energy frequency distribution histograms in operational phase.

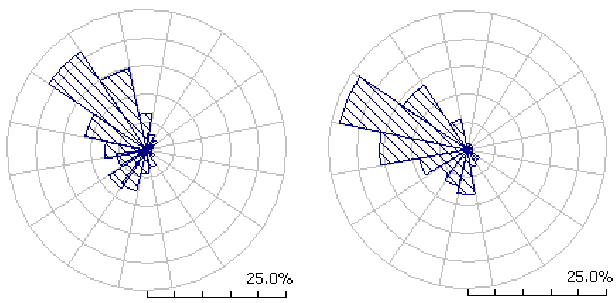

Figure 5. Annual wind direction roses in design phase (left) and operational phase (right).

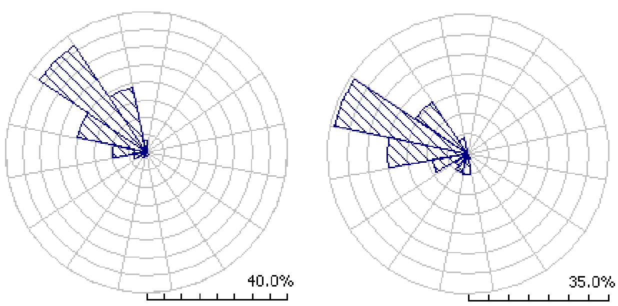

Figure 6. Annual wind energy roses in design phase (left) and operational phase (right).

utilized to calculate the wind regime data of two phases respectively. During the calculation, wind farm digital maps, wind turbines arrangement and wind generator models were based on the documents in design phase while standard power curves were adopted under standard density.

1) Comparison of equivalent full load hours

The average equivalent full load hours of program WTG850C from design phase are 2361, while program WTG1500D are 2497, full load hours during the actual operation are 2711. However, some data are vacant and required to be fixed before using due to the wind farm monitoring system communication problem. Moreover, the recommended scheme was not adopted during the actual construction. Thus this value is only for reference.

2) Comparison of wind turbine availability

According to statistics in normal time of wind turbines in the wind farm production & technology department record sheets, the wind turbine availability ratio can be calculated, as shown in **Table 1**.

As can be seen in **Table 1**, the efficiency of 28^{th} unit wind turbine is too low, only 32.1%. The number of normal hours is 0 by querying the data of 28^{th} unit from January, 2009 to August, 2009. After consultation with operation personnel, the 28^{th} unit had been a long time downtime, but did not appear for several months long, which indicated lack of data records. After removing the effects of the 28^{th} unit, average utilization rate of wind turbines in the wind farm was up to 95.81%. The utilization rate (95%) in the feasibility study phase is consistent with the actual situation.

3) Dispatch of load limitation

During the operation of the wind farm, scheduling notification of load limitation generally had great influence on the energy production of wind farm. According to commands on scheduling load limit and electricity loss caused by them in the statistics records of the wind farm, major load limit appeared in January, February, March, November, December and some other months with good wind conditions, which led to a certain impact on energy production. The loss of generated capacity by dispatching load limitation was accumulated to 16,964 MWh in sum from October, 2008 to September, 2009. But this record is the total power loss of three wind farms, it is impossible to identify the specific issue of power loss in a certain wind farm, because there are not clearly marked specific restrictions in the records. The loss of power due to the scheduling load limit in the first project wind farm added up to about 4.3MWh if pro rata estimated. Because grid construction is lagging behind, load limit of wind farms in Inner Mongolia and the Northeast is much more serious, especially during heating seasons, and these months are just the time with the best wind conditions. Prior to requirements in power grid construction, variations of generating capacity caused by this factor should be noted in the feasibility study.

4) Rough calculation of energy production of the wind farm

There are differences in the location of wind towers and siting of wind turbines between the actual design phase and the operational phase. The wind farm energy productions were calculated by WAsP, considering four cases in the evaluation: the wind regime and the site election both in design phase; the wind regime in design

Table 1. Availability of various units of wind farms (%).

Unit NO.	1	2	3	4	5	6
Use Ratio	97.52	99.24	86.93	98.24	99.38	97.26
Unit NO.	7	8	9	10	11	12
Use Ratio	96.24	99.41	99.81	99.91	99.21	83.07
Unit NO.	13	14	15	16	17	18
Use Ratio	98.62	99.28	96.66	70.35	99.22	98.74
Unit NO.	19	20	21	22	23	24
Use Ratio	94.32	98.68	99.94	95.54	97.68	94.46
Unit NO.	25	26	27	28	29	30
Use Ratio	92.25	98.00	95.31	32.10	99.42	99.09
Unit NO.	31	32	33	34	35	36
Use Ratio	97.59	96.68	90.53	97.11	96.53	91.14

phase and the site election in operational phase; the wind regime in operational phase and the site election in design phase; the wind regime and the site election both in operational phase.

Case NO.1: the wind regime and the site election both in design phase. The calculation shows that the annual net energy production is 110,854 MWh of 36 wind turbines totally.

Case NO.2: the wind regime in design phase and the site election in operational phase. The results indicate that the total net energy production is 87,456 MWh of 29 wind turbines, and the net energy production of 36 wind turbines is 118,566 MWh calculated in proportion. The energy production is slightly lower than that in case NO.1, indicating that the siting in design phase is superior to the actual siting.

Case NO.3: the wind regime in operational phase and the site election in design phase. The calculation eventuated that the annual net energy production was 113,311 MWh of 36 wind turbines.

Case NO.4: the wind regime and the site election both in operational phase. The results indicate that the total net energy production is to 89,174 MWh of 29 wind turbines, and the net energy production of 36 wind turbines is 110,699 MWh calculated in proportion. Layouts of wind turbines in design phase were further proved better than the actual layout scheme.

Through the calculation of four cases, the net total energy production calculated by WAsP is between 108,566 MWh to 113,311 MWh, and discrepancy between the maximum and minimum values is 4745 MWh.

5) Energy production and energy consumption within the wind farm

According to report statistics posted by the Electricity Production Technology Department, the monthly energy production and on-grid energy production in the first project of the wind farm are listed in **Tables 2** and **3** (from October, 2008 to September, 2009).

The generating capacity and wind speed were presented to do comparison in **Figure 7**.

Through the comparison, the wind speed trend is consistent with energy production exactly. Assessment of wind regimes reflects the average wind speeds in January and February are lower than that in representative year of design phase, as shown in **Figure 2**. The uniformity of energy production with monthly wind speeds, the wind measurement data during operational phase are credible.

The annual generation capacity of the wind farm is 87,892 MWh and the on-grid energy production is 86,831 MWh by calculating monthly generating capacity available. On-grid energy production accounts for 76.63% - 79.98% of the rough calculation power generation. In the feasibility report, total generating capacity reduction rate, 32%, is higher than the actual one 20.02% - 23.37%. Therefore, appropriate adjustment of the reduction factor should be considered in the future feasibility study.

The energy consumption inside the wind farm was shown in **Figure 8** using the data of energy production and the on-grid energy production.

Table 2. First project energy production of the wind farm (10 MWh).

Month	10	11	12	1
Energy Production	806.86	1078.00	1170.96	854.17
Month	2	3	4	5
Energy Production	860.18	947.50	627.29	761.12
Month	6	7	8	9
Energy Production	654.79	276.39	232.36	519.64

Table 3. First project on-grid energy production of the wind farm (10 MWh).

Month	10	11	12	1
Energy Production	799.13	1064.13	1156.34	841.81
Month	2	3	4	5
Energy Production	849.35	935.21	618.93	753.83
Month	6	7	8	9
Energy Production	648.10	273.20	229.20	513.94

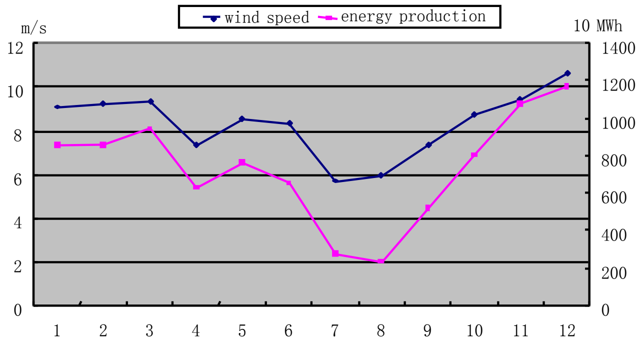

Figure 7. Comparison between wind speed and energy production.

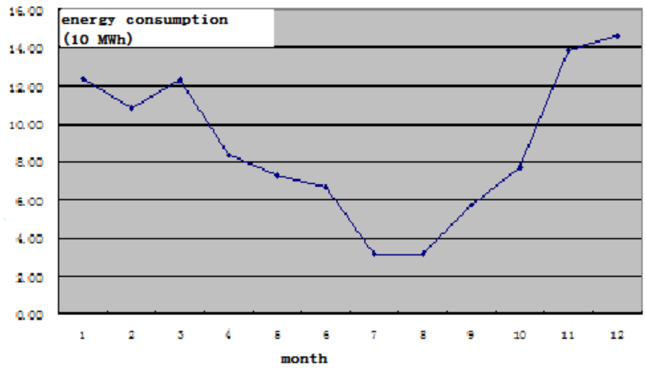

Figure 8. Energy consumption in the wind farm.

Total energy consumption and loss venue are 1061.100 MWh, accounting for 1.21% of the actual energy production of the wind farm, and accounting between 0.94% - 0.97% rough-estimated generating capacities. Energy consumption reduction, in feasibility report, is 5%, which is relatively higher than the actual one.

6. Conclusions

With integration of the actual operating data associated with the relevant information in design phase of a certain wind farm in northern China, wind resource assessment, micro-siting, power generation calculation were post-evaluated and the following conclusions were obtained:

1) The revised annual wind regimes at the feasibility study phase and the actual operation phase (October, 2008 to September, 2009) are generally agreed, indicating that the wind regimes of representative year is a good response to the characteristics of local wind conditions.

2) The wind speed and wind energy during actual operational phase are slightly lower than the wind conditions of the representatives in the feasibility study stage, which are possibly caused by the impacts of the long-term trend of the reduced wind speed or special wind regime of this year. Specifically, the high wind speed segment reduced (annual wind speeds in January and February according to the measured data are lower than those of representative years), and low wind speed segment unchanged or slightly increased. Due to the consideration including these factors should be taken when determining the models of WTGS.

3) The number of wind speeds lower than the representative years', in January and February during actual operation, is large. Wind speeds were low indeed rather than measurement problems based on the observation of energy production changes over the same period of the wind farm. There are two statuses may lead to phenomena: Firstly, the revised wind speeds in January and February of the representative year have positive deviation; Secondly, wind speed data collected in the January and February of the year in operational phase are relatively low. The data of additional years are required with further comparison to confirm.

4) Through the comparison of different wind conditions and layouts of wind turbines, design of micro-siting in the feasibility study is superior to the actual distribution scheme.

5) The average wind turbine availability comes to 95.81% according to the records, while the estimated value in the feasibility study stage is 95%, whose reduction is more accurate.

6) Energy consumption inside accounts for 0.94% - 0.97% of rough-estimated energy production of the wind farm. The energy consumption reduction of the venue is 8% in the feasibility study, higher than the actual situation, recommending a cautious consideration for future design.

7) According to the annual energy production during actual operation of the wind farm and re-estimated rough calculation of the power output, the actual value of energy production is lower than the rough calculation about 20.02% - 23.37%. The reduction of total reduction in feasibility study stage is 32%, which is a little higher. Therefore, considering the twenty-year life of the wind farm, selection of the reduction factors should be further investigated.

To obtain more scientific results, the increasing number of wind farms will be further post evaluated in an extended period of time.

Acknowledgements

The authors gratefully acknowledge the support from National Nature Science Foundation of China for the Program: Physical Method Study for Wind Power Prediction based on CFD Numerical Simulation Database (NO.51206051).

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