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Comprehensive evaluation index system for wind power utilization levels in wind farms in China

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ABSTRACT

China's wind power installed capacity is the largest in the world, but the utilization of wind power equipment is not very good, far behind USA. In this paper, the development of China's wind power is reviewed, and the present wind power curtailment restricts the sound development of China's wind power industry. The characteristics of China's wind farm are summered. With the insatiability and intermittence, wind power is not welcome to China's electric grid, and large-scale wind power construction does not match with the existing power grid, therefore, wind power curtailment is serious and the level of wind power utilization is very low. To solve the wind power curtailment rationing problem, in this paper, combined with the characteristics of China's wind farm operation, the wind power utilization level evaluation index system has been built, reflecting the wind resource characteristics, wind power equipment type, wind power output, wind power curtailment, grid technology, operation management and so on. Taking Hami wind farm in Xinjiang province as an example, wind power utilization level is evaluated comprehensively, combined the improved analytic hierarchy process (IAHP) analysis and fuzzy comprehensive evaluation method (FCEM). The results show that the establishment of wind power utilization level comprehensive evaluation index system is helpful to find the main factors which effect the level of wind power utilization and improve the wind power field operation, which can provide reference for the planning and design of wind farm, and the results have certain value on theoretical significance and engineering application.

1. Introduction

The wind power industry in China has been rapidly developing in the past 10 years under the favorable new energy policy support of the country, which offers unique advantages [1,2]. With the considerable development of the population and economy, China now faces a serious energy crisis and severe environmental pollution [3,4]. According to the Global Wind Energy Association statistics, the new wind power installed capacity of China in 2014 was 23,196 MW, which represents a 44.2% increase relative to the recorded value in 2013 [5]. Despite this large installed capacity, the country's wind power utilization rate remains low.

The year 2010 was an important turning point in China's wind power industry. In 2010, China's total installed capacity of wind power surpassed that of the USA, thereby ranking China first in the world. However, the phenomenon of wind power curtailment appeared. The accumulative power of wind turbines in the country reached 44.7 GW, but 31% of these wind turbines could not be interconnected. The total amount of wind power curtailment reached 3.94×10^9 kW h at the curtailment rate of 10%. Since then, China's wind power industry has been struggling between distress and glory [2,4,6].

The wind power curtailment of China from 2010 to 2014 is shown in Fig. 1. The most serious case of wind power curtailment occurred in 2012. From 2010 to 2014, the total wind power curtailment reached 20.82×10^9 kW h and the curtailment rate was 17.12%. Consequently, the direct economic losses reached 11.4 billion yuan [2,5,6].

China's wind resources are concentrated in large scales and are far away from the load center. Wind power curtailment is mainly concentrated in North, Northeast, and Northwest China, the southeast coast, and other remote areas. Most of these areas are located at the end of the power grid [2,7,8]. Thus, the power grid is relatively weak there. The wind power construction is faster than the growth of the local power accommodation capacity, and the wind power integration scale exceeds the power export capacity of the power grid [7–9].

The actual output of wind farms in China has yet to match expectations because of certain factors, such as wind resources, performance of wind turbine equipment, management of wind farm operations, system disposal capacity, one-sided pursuit of installed

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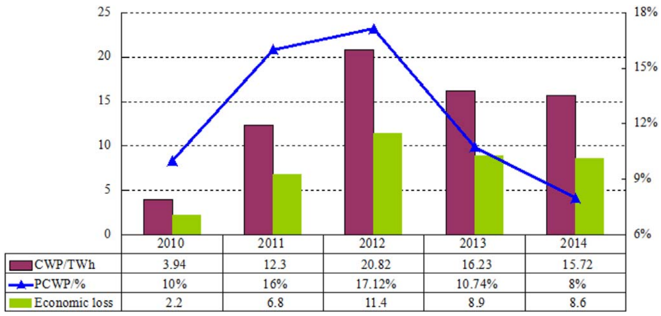

Fig. 1. The wind power curtailment of China from 2010 to 2014 [2,4,5]. (Source: CWEA, GWEC. CWP: Curtailed Wind Power, PCWP:Proportion of Curtailed Wind Power, Economic loss: ￥10^9 yuan).

capacity and the efficiency ignored [10–12].

The method of multiple indexes is used to analyze the utilization level of wind power, because it is closely related with many factors. In the literature [2,13], three levels of wind power utilization index system is constructed, and the system includes basic indicators, the development of scale indicators and the use of efficiency indicators. Among them, the annual wind power generation accounted for the proportion of power consumption and wind power installed capacity accounted for the proportion of total net installed capacity highlight the scale of the development of wind power in various regions of our country, and the annual utilization hours index is a comprehensive embodiment of accommodating wind power in the power system.

For the evaluation methods, domestic and foreign scholars have proposed dozens, and several methods have been widely used, such as principal component analysis method (PCAM), Delphi method, the grey comprehensive evaluation method (GCEM), artificial neural network method (ANNM), analytic hierarchy process (AHP) and fuzzy comprehensive evaluation method (FCEM), and so on, the advantages and disadvantages of these methods as shown in Table 1.

Therefore, in this paper, the wind farm operation comprehensive evaluation model is established, combined the improved analytic hierarchy process (IAHP) and fuzzy comprehensive evaluation method (FCEM), the status of the wind energy farm operation is comprehensively evaluated. The results can facilitate the operation and planning of wind farms and promote the scientific development of the wind power industry.

Table 1
Comparison of several common comprehensive evaluation methods.

Evaluation methods	Advantages	Disadvantages
PCAM	Effective reduction of the number of original variables by using dimension reduction ideas, to achieve the effect of fast convergence speed.	When the principal component factor is positive and negative, the comprehensive evaluation is not clear.
Delphi	Give full play to the role of experts, benefit by mutual discussion , high accuracy	The process is complex, and the time is long.
GCEM	This method is applicable to the problem of accurate and objective index.	Only judge the pros and cons, do not reflect the absolute level.
ANNM	This method can deal with nonlinear and non local large scale complex systems, and has strong adaptability and fault tolerance.	Requires a large number of samples and marginal conditions
AHP	Level of clarity and ease of analysis	Evaluation of the object of the factors can not be too much, generally not more than 9
FCEM	This method can solve the problem of fuzziness and uncertainty.	If the indicators do not have mutual independence, it is difficult to solve the information related issues

2. Wind power in China

China is a large country with excellent wind energy production that reaches approximately 3.226 billion kW. With technological advancement, the wind energy reserves of the country amount to 1 billion kW, which is close to that of the USA. Hence, China is regarded as one of the five major wind power producers in the world [14–16].

The distribution of the annual duration of wind speed above 3 m/s in China is shown in Fig. 2 [1,2]. Wind energy resources depend on wind energy density and the annual cumulative hours of wind energy. The distribution of the average wind power density in areas with a height of 70 m is shown in Fig. 3 [17].

Wind energy resources are greatly influenced by the terrain. In China, wind energy is mainly distributed in the following areas [18–20]:

(1) Southeast coast and its islands, which serve as the largest wind energy resources;
(2) In ner Mongolia and Gansu in the north, which are major wind energy resources;
(3) Heilongjiang and Eastern Jilin and the Liaodong Peninsula coast, which also provide a considerable amount of wind energy;
(4) The Qinghai Tibet Plateau and the three northern regions of the northern coastal area, which serve as a large wind energy sources;
(5) Yunnan, Guizhou, Sichuan, Gansu, Southern Shaanxi, Henan, Western Hunan, the mountainous areas of Fujian, Guangdong, Guangxi, and the Tarim Basin, which feature the smallest wind area.

With China's recent focus on the development of nine 10 million kW class wind power bases, nine wind power bases have been built in Hami in Xinjiang, Jiuquan in Gansu, and in other areas, as shown in Fig. 4. The development of these wind power bases follows the wind resource distribution in China and the layout involving the "building of a large base for a large power grid." The nine large wind farms are expected to reach an installed capacity of more than 79 GW in late 2015; this value should account for more than 75% of the total wind power of the country [21,22].

At present, China's wind power industry is a global leader in the field of wind power development. Since 2010, the total wind power installed capacity of the country has been ranked first [2]. By the end of 2012, the wind power of China had reached 13.5 TWh, thereby making wind power the third largest type of power supplied by the country, with thermal power and hydropower topping the list [3,4].

By the end of 2014, the cumulative wind power installed capacity had reached nearly 114.6 million kW, which accounted for 7% of the total power installed capacity during that period. Moreover, the grid connected capacity reached nearly 1 million kW, which corresponded to the operation of nearly 7 million wind power units, i.e., more than 1500 wind farms. Fig. 5 shows the wind power development in China from 2001 to 2014 [2–4].

According to the China Wind Energy Association statistics [23], the most pressing problem of the Chinese wind power industry is wind power curtailment. The details of the wind power curtailment of China in 2014 are illustrated in Fig. 1. During the said period, the total wind power curtailment reached 70 billion kWh, which corresponded to a direct economic loss of nearly 40 billion yuan over the past five years. As a result of the rejection of wind power turbines for use in the power grid, the poor power supply structure, and the limited regulation capacity of the power system, the output of wind power turbines is restricted, and wind power equipment is even shut down. These conditions increase the severity of the rationing of disposable wind power. Table 2 presents the wind power curtailment in major Chinese provinces in 2014 [24]. The rate of wind power curtailment reached