Effects of atmospheric stability on wind resource characteristic parameters

Ma Xiaomei, Li Tao, Liu Yongqian, Han Shuang

Department of Physics and Electronic Engineering, Qinghai Normal University, People’s Republic of China
E-mail: ncepumxm@163.com

Published in The Journal of Engineering; Received on 5th October 2017; Accepted on 1st November 2017

Abstract: The mean wind speed, wind speed distribution, wind shear exponent and wind power density would be affected by terrain, atmospheric stability and equipments, are important parameters in the process of wind resource assessment. However, Conventional methods have always ignored the effects of atmospheric stability, which might make results deviate from the actual situation. The main purpose of this work is to present effects of atmospheric stability on wind resource parameters. Taking 4 years’ measured data as case study, six parameters in wind resource assessing are calculated under different atmospheric stabilities; influential rules of above assessing parameters under varying atmospheric stability are analyzed respectively in order to obtain a systemic relationship between atmospheric stability and wind resource characteristic parameters which is tested by 5th year’s data. Based on these studies, a hub height wind speed extrapolation model is proposed. This model could use different wind shear exponent under various atmospheric stabilities during wind speed extrapolating, rather than an average wind shear for the whole wind farm. In such way, much accurate extrapolating hub wind speed in wind resource assessing is employed, and errors in wind resource assessment might decline. Results validate the simplicity, accuracy and practicality of the proposed method.

1 Introduction

Wind power generation has the cube relation with respect to wind speed. An accurate understanding of wind characteristics is the initial and critical step to all aspects of wind energy exploitation [1] including assessing wind energy resources, evaluating economic viability of wind farm projects, deploying wind turbines, wind turbine designing and even power system planning [2]. Wind resource assessment enables project developers and investors to take a ‘go/’no go’ decision with respect to that project and at a notional or regional level it enables the concerned government or agencies involved to figure out if there is enough potential to take advantage of wind energy and is such potential to be developed on a large scale, requires some policy frameworks. To the major wind turbine suppliers, wind resource assessment at regional level can be used to decide on the wind turbine generation types that should be designed and marketed in that region and similar other regions of the world.

In the process of wind resource assessment, wind speed at hub height is an important factor for wind speed reflects wind resource directly [3]. However, the lack of reliable and accurate wind measurements is hampering the development of new wind power projects. The tradition convention is to extrapolate observed wind speeds from the available heights to wind turbine hub heights [4, 5]. Nowadays, this has become more challenging due to the increasing size of wind turbines capacity and hub heights. Wind profile (or wind shear) in the first 100m is highly affected by the site where measurements are made [6], as the shape of wind profile is affected by surface roughness, time, location and atmospheric stability [7–10]. In particular, wind shear is strongly affected by atmospheric stratification, and therefore it varies notably through time, i.e. by hour of a day and month/season of year as well as from a year to another [11, 12]. However, a majority of assessment processes treat atmospheric stability as a tiny factor which was often ignored.

Through the years, incorporating atmospheric stability into wind resource assessment modelling is becoming common [13], and several researches, focusing on the effects of atmospheric stability on wind resource characteristic parameters such as wind speed, wind profile and wind shear exponent, have been made [14–19]. However, there is no uniform analytic expression for wind speed variation with height, which could be valid for all stability conditions [20]. In particular, further study of the effects of atmospheric stability on other wind resource characteristic parameters have not been obtained, which would reduce the possibility of assessing wind resource scientifically and reasonably.

The main purpose of this work is to analyse and apply the effects of atmospheric stability on wind resource characteristic parameters, particularly to present a wind speed extrapolation method recognising atmospheric stability. Taking the 5 years’ wind measurements at various heights from a meteorological station in CO, USA as case study, wind data from the first 4 years (2007–2010) were used to analyse site meteorological, stability condition and effects of stability on wind resource characteristic parameters such as wind profile, wind shear exponent, wind power density, wind roses and wind speed distribution, which has laid a solid foundation for putting forward to the model, applied in extrapolating hub height wind speed by taking atmospheric stability into account, while the latter (2011) to test the performance of the proposed model.

The model has broken the traditional technological path of wind resource assessment, which takes advantage of the permanent evaluation index. Moreover, it has been validated by extrapolating observed wind speed from the available height to hub height. The results show that the proposed model which has considered atmospheric stability will improve the accuracy of wind resource assessment, particularly, the model seems to be more effective under unstable and neutral conditions.

2 Data description

In this paper, wind measurement data in CO, USA are used to learn the effects of atmospheric stability on wind resource characteristic
parameters. Wind data are recorded for a consecutive 5 years (from 01 January 2007 0:00 to 31 December 2011 23:00) from a meteorological station established by National Renewable Energy Laboratory. The latitude, longitude and elevation of this wind measurement mast are 39° 54' 38.34"N, 105° 14' 5.28"W and 1855 m above mean sea level, respectively. Wind speed and wind direction are measured at various heights (including 2, 5, 10, 20, 50 and 80 m). In case study, data in the first 4 years (2007–2010) were used to assess wind resource characteristics, and overall mean value of all height intervals have been calculated. Moreover, height interval is also a significant factor for wind shear exponent. Taking the unstable condition of 2007 as an example, wind shear exponent of 2–5 m height interval is 0.05, while calculated by height interval of 10–20 m, the result comes

3 Wind resource characteristic parameters in different stability

To study the effects of atmospheric stability on wind resource characteristic parameters, atmospheric stability parameters have been calculated to obtain the classification. In this part, wind profile, wind shear exponent, wind speed distribution, wind power density and wind roses have been analysed under different atmospheric stabilities.

3.1 Wind profile

Wind profile reflects the wind speed variation with height. The power law is often used in wind power assessments where wind speeds at the height of a turbine (~50 m) must be estimated from near-surface wind observations (~10 m) or where wind speed data at various heights must be adjusted to a standard height prior to use. On the basis of Monin–Obukhov (M–O) similarity theory [21], wind profile under different stabilities can be calculated as

$$v = \frac{u_*}{k} \ln \left( \frac{z}{z_0} \right) - \psi_m \left( \frac{z}{L} \right)$$

(1)

where, \(v\) is the friction velocity; \(k\) is von Karman constant; \(z\) is the height; \(z_0\) is the roughness length and \(L\) is the M–O length.

Stable condition (\(z/L<0\)): \(\psi_m = -4.7 \left( \frac{z}{L} \right)\)

Neutral condition (\(z/L\approx 0\)): \(\psi_m = 0\)

Unstable condition (\(z/L<0\)): \(\psi_m = -\frac{4}{3} \left( \frac{z_0}{L} \right)^{2/3} \ln \left( \frac{1 + 15 \left( \frac{z_0}{L} \right)^{1/3}}{1 + 15 \left( \frac{z}{L} \right)^{1/3}} \right) - 2 \left[ \arctan \left( \frac{z}{z_0} \right) - \arctan \left( \frac{z_0}{z} \right) \right] \)

where \(z_0 = [1 - 15 \left( \frac{z_0}{L} \right)^{1/3}]^{1/4} \); \(\xi = [1 - 15 \left( \frac{z_0}{L} \right)^{1/3}]^{1/4} \)

On the basis of 2007–2010 wind data, hourly M–O length is calculated by (1), and wind profiles of each year under different atmospheric stabilities have been obtained by yearly average wind speed, as shown in Fig. 1.

As shown in Fig. 1, atmospheric stability has a great influence on wind profile, and the distribution rules of each year almost accord with each other, namely for a given height, the wind speed increases gradually when atmosphere varies from unstable, neutral to stable state. However, when the atmosphere is very stable (F), inversely wind speed would be smaller. Obviously, in the process of wind resource assessment, ignoring the influence of stability, that is, assuming that atmosphere keeps neutral, will bring error.

3.2 Wind shear exponent

Wind shear exponent is a comprehensive parameter which is influenced by wind speed, surface roughness and atmospheric stability.

Hellman proposed a simple and practical equation for wind profiling [22]

$$v_z = v_0 \left( \frac{z}{z_0} \right)^{\alpha}$$

(2)

where \(\alpha\) is the wind shear exponent, depending on wind speed, roughness, atmospheric stability, the height interval etc. [23]. On the basis of M–O similarity theory and previous studies, Panofsky and Dutton [24] proposed a semi-empirical formulation to estimate \(\alpha\) as a function of atmospheric stability and \(z_0\)

$$\alpha = \phi_m (\xi/L) / [\ln(\xi/z_0) - \psi_m(\xi/L)]$$

(3)

where \(\psi_m\) is the stability function.

Wind shear exponent under different stabilities of the first four years has been calculated. To reduce the error caused by choosing of height interval, wind shear exponent of each height interval and overall mean value of all height intervals have been calculated in this example. A preliminary analysis has been performed to assess 2007–2010 wind shear exponent of each height interval under different stabilities, and the values summarised in Fig. 2: wind speed profile estimated by power law using a constant wind shear exponent is a bad oversimplification, and that wind shear exponent must be treated as a statistical parameter varying by stability, roughness, wind speed, time and wind shear exponent is proved to increase from unstable to stable conditions, as they are 0.07, 0.15, 0.20 for unstable, neutral and stable conditions, respectively. Moreover, height interval is also a significant factor for wind shear exponent.

Fig. 1 Wind profile under different stabilities (2007–2010)

Fig. 2 Wind shear exponent under different stabilities (2007–2010)
to 0.12. Another result can be concluded that in this case wind shear exponent calculated by height interval of 10–80 m is closest to average value under any stability. In conclusion, during calculating wind shear exponent, considering the influence of atmospheric stability and choosing the reasonable height interval have a vital significance to enhance the extrapolation accuracy.

3.3 Wind speed distribution

In probability theory and statistics, the Weibull distribution is a continuous probability distribution. If wind speed distribution is described as Weibull distribution, the cumulative frequency less than a certain wind speed is calculated as

$$P(V \leq V_g) = \int_{v}^{\infty} \left( \frac{c}{V_g} \right)^k \frac{k}{V_g} e^{-\left( \frac{c}{V_g} \right)^k V} \, dv = 1 - e^{-\left( \frac{c}{V_g} \right)^k V}$$  

(4)

where $c$ is the scale coefficient and $k$ is the shape coefficient of wind speed distribution. Fig. 3 reflects $k$ and $c$ variations under different stabilities through years, which proves that under unstable conditions, $k$ and $c$ are mostly the same in each year, where during stable conditions the values differ from one year to another.

From these results, a confirmation of description is found that under unstable conditions, the Weibull distribution shows the highest accuracy, and neutral stability wind speed distribution is roughly modelled by Weibull distribution while it confirmed to show a dramatically unrealistic pattern under stable conditions. That is, Weibull distribution gives a reasonable accurate and better representation of wind speed distribution, at least for unstable and neutral conditions.

Fig. 4 shows the Weibull wind speed distribution obtained by parameters in Fig. 3, where observed that the more stable of the atmosphere, the larger of the mode.

![Fig. 3 Wind speed distribution parameters under different stabilities (2007–2010)](Image 49x90 to 275x220)

![Fig. 4 Wind speed distribution under different stabilities (2007–2010)](Image 69x274 to 254x395)

As wind speed Weibull distribution can also be used to calculate mean wind speed, this part is arranged to compare mean wind speed of the whole year calculated by different wind speed distributions.

On the basis of 2011 wind data at the height of 80 m, three aspects have been chosen to calculate mean wind speed of the whole year to finish the comparison: (a) calculated by Weibull distribution without considering atmospheric stability of the whole year; (b) first calculating Weibull distribution under stable, neutral and unstable conditions, then obtaining mean wind speed based on three stabilities; (c) measured data. The results have been shown in Table 1.

From Table 1, mean wind speed of the whole year calculated by method (b) is equal to 4.77 m/s, which is closer to the measured result, 4.71 m/s, while method (a) which has ignored the atmospheric stability has less accuracy. Therefore, atmospheric stability is an important factor which would influence wind resource assessment in many aspects, which has emphasised the necessity of considering it in wind resource assessment.

3.4 Wind power density

The wind farm sitting is the primary work in the construction of wind power plant, which includes macro and micro sitting. During the macro sitting stage, the first request is a good quality of wind energy, that is, with higher wind speed, larger wind power density, higher available hours etc. Wind resource characteristic parameters could be influenced by the state of atmospheric stability through the research in this paper. Namely, assuming atmosphere keeps neutral would bring error in the assessment process, which would affect economic benefits of wind farms.

On the basis of 2007–2010 data, wind power density under different stabilities have been calculated, as shown in Fig. 5. From 2007 and 2009 data, wind power density increases from unstable to stable conditions on the whole, and only a few moments do not meet this rule. Also, an unstable condition in 2010 keeps

| Atmosphere stability | $c$  | $k$  | Mean wind speed $V$, m/s |
|----------------------|-----|-----|-------------------------|
| no consideration     | 4.8 | 1.21| 4.46                    |
| stable               | 6.4 | 3.95| 4.77                    |
| neutral              | 5.71| 3.31| 4.71                    |
| unstable             | 3.9 | 1.90| 4.71                    |

| measured data        | —   | —   | 4.71                    |

This is an open access article published by the IET under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0/). doi: 10.1049/joe.2017.0415
minimum all the time, which accords with the aforementioned law. However, a larger value of wind power density appears alternately between stable and neutral conditions in 2010. The reason for this phenomenon may be the stable condition in 2010 tends to slightly stable (59% of M–O length are in range of unstable, and the yearly average M–O length is −82.0429, which is more likely to belong to slightly unstable compared with neutral condition), which do not have very obvious distinction with neutral case, in addition the classification of atmospheric stability criteria is not absolute. Finally, it is possible to bring this result.

In general, the more stable of the atmospheric stability, the larger of the wind power density. Therefore, the region with larger proportion stable atmosphere contains better wind power quality during macro sitting.

3.5 Wind roses

A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location, while wind energy rose reflects the variation of wind energy. Both the wind rose and wind energy rose play important roles in the process of wind resource assessment and practical engineering layout. On the basis of data of 2007–2010 years, the wind rose and wind energy rose containing atmospheric stability proportion of each direction at 80 m have been shown in Figs. 6 and 7, which explains the possible reason of the difference between wind rose and wind energy rose.

Taking 2007 result as an example, predominant winds are from North–West (NW), WNW, South–S–East (SSE) and S in wind rose, while in wind energy rose most frequent winds are from NW and WNW, in particular, wind energy of S and SSE directions turn to much smaller. The reason might be found in wind speed under different stabilities. Even though S and SSE occupy large proportion in wind rose, most of them are unstable cases which with low wind speed. As a result, it should be concluded that dominant wind direction does not mean dominant wind energy direction. The proportion of different atmospheric stabilities should be taken into account.

3.6 Summary

From the former researches, it can be concluded that atmospheric stability can influence wind resource characteristic parameters to a certain extent, and ignoring the aforementioned effects might affect the accuracy of wind resource assessment. On the basis of 2007–2010 wind data, wind shear exponent and wind distribution parameters under different stabilities have been summarised in Table 2.

It is to be noted that the summarised data in Table 2 has laid a foundation for modelling. Furthermore, features of the atmosphere under different stabilities have been reflected obviously.

4 Wind speed extrapolation model considering stability

To improve wind resource assessment accuracy, increase the economic benefits of wind power engineering, and provide a reference for wind turbine selection, this paper has proposed a wind speed extrapolation model considering atmospheric stability. The main purpose of the model is to take factors which influence the vertical wind speed distribution into account during extrapolation as more as possible. In wind farm feasibility study, wind resource at wind turbine hub height is generally estimated by direct use of reanalysis time series [25]. However, the complex variation of the atmosphere through time, i.e. by an hour of a day even from a second to another, makes it difficult. The model regards hourly atmospheric parameter as a standard of atmospheric classification. Fig. 8 has shown the flowchart of the model.

5 Case study

To validate the accuracy and practicability of the proposed wind resource assessing framework and wind speed extrapolation method, two methods were used to extrapolate hub height (80 m) wind speed from 10 m: (i) widely used wind speed extrapolation

Table 2 Wind resource parameters under different stabilities

|          | Unstable | Neutral | Stable |
|----------|----------|---------|--------|
| wind shear | 0.07     | 0.15    | 0.20   |
| c        | 3.77     | 6.78    | 7.65   |
| k        | 1.96     | 3.72    | 3.21   |
Table 3 Wind resource parameters by two methods

| Method (1) | Method (2) | Measured |
|------------|------------|----------|
| mean $v$, m/s | 5.01 | 4.78 | 4.71 |
| $c$ | 5.57 | 5.31 | 5.24 |
| $k$ | 1.56 | 1.38 | 1.42 |

![Graph showing comparison of wind speed extrapolation methods](image)

Fig. 9 Hourly RMSE by two extrapolation methods of the whole year (2011)

method (regardless of stability, and treat wind shear exponent as a mean value of whole year which is equal to 0.123) and (ii) the proposed model recognizing stability. On the basis of the 2011 measured wind data, several wind resource characteristic parameters have been calculated by aforementioned methods, as shown in Table 3. To reduce the error brought by choosing height interval, the extrapolation process makes use of 10–80 m height interval based on the previous study in this paper.

Focusing on different extrapolation methods, annual mean wind speed has different results, as they are equal to 5.01 and 4.78 m/s for methods (1) and (2), respectively, while the observed result is 4.71 m/s. Compared to methods (1) and (2), it is obvious that the result calculated by the model proposed in this paper is closer to the measured data, both hub height wind speed and wind speed distribution parameters.

A commonly used statistical error evaluation index is employed to judge the performance of the proposed wind speed extrapolation considering atmospheric stability. Root-mean-square error (RMSE) is calculated for all validation periods, which can give a better evaluation of extrapolation error [26].

On the basis of 2011 data, the hourly RMSE of hub height wind speed by aforementioned extrapolation methods has been shown in Fig. 9. Some conclusions can be drawn from Fig. 9. The model has effectively reduced the RMSE of hub height wind speed, especially hours of 9–16. The possible reason would be that the proportion of unstable atmosphere is larger in this area. Fig. 9 reflects that taking atmospheric stability into account can make extrapolation results closer to the true value. Above all, the presented model has considered various factors influenced wind speed, especially atmospheric stability and the results are more approached to the actual value, which can effectively improve the accuracy of the wind resource assessment.

6 Conclusions

This paper presents a framework for wind resource assessment accounting for atmospheric stability. The quantitative index of wind resource characteristics including mean wind speed, wind speed distribution, wind shear exponent and wind power density are calculated in various atmospheric stabilities. It is to quantify the stability effects of wind resource and also to validate the necessity of atmospheric stability consideration. On the basis of these, a wind speed extrapolation model accounting for atmospheric stability is proposed to mitigate the problem of extrapolating hub height wind speed, generating missing observation data or correcting invalid data in practical engineering.

In the case study, 5 years wind measurements at various heights from a meteorological station in CO, USA are used. The results show that the proposed wind resource assessment method has better performance than the traditional method without consideration of atmospheric stability. The proposed extrapolation method can improve the accuracy of wind data examination and reconstruction. Besides, following conclusions can be drawn from the atmospheric stability analysis:

(i) The state of atmospheric stability has a significant influence on the wind resource characteristic parameters. Wind speed, wind power density and wind shear exponent show the maximum in stable condition, while the values are the minimum in unstable condition. In addition, the larger corporation of the stable in a certain direction of wind rose, the larger of the wind energy. More importantly, in unstable condition, the Weibull distribution shows the highest accuracy, and neutral stability wind speed distribution is roughly modelled by Weibull distribution while it confirmed to show a dramatically unrealistic pattern under stable condition. When it comes to wind profile, different atmospheric stabilities lead to different forms of wind profiles.

(ii) Consideration of atmospheric stability could effectively improve the accuracy when extrapolating hub height wind speed. RMSE has been reduced by 0.18 m/s under the unstable condition and 0.06 m/s under stable condition, while the difference between extrapolated and measured mean wind speed at hub height has been reduced by 0.23 m/s.

(iii) The above conclusions suggest that temperature sensors should be installed at least two heights to calculate atmospheric stability parameter accurately during installing wind measurement mast. In this way, the effects of atmospheric stability on wind resource assessment could be taken into account, and the accuracy of wind resource assessment could be improved.

7 References

[1] Burton T., Sharp D., Jenkins N., et al.: ‘Wind energy handbook’ (John Wiley & Sons Ltd., California, U.S.A., 2007)
[2] Gong Q.F.: ‘Analysis of several important parameters in wind resource assessment’, J. Inner Mongolia Petrochemical Ind., 2012, 15, pp. 63–65
[3] Giovanni G., Sauro S.: ‘Comparing methods to calculate atmospheric stability-dependent wind speed profiles: a case study on coastal location’, Renew. Energy, 2011, 36, pp. 2189–2204
[4] Sucevic N., Djurisic Z.: ‘Vertical wind speed profiles estimation recognizing atmospheric stability’. 2011 Tenth Int. Conf. Environment and Electrical Engineering (EEEIC), Rome, 8–11 May 2011
[5] Song M.X., Chen K., He Z.Y., et al.: ‘Wind resource assessment on complex terrain based on observations of a single anemometer’, J. Wind Eng. Ind. Aerodyn., 2014, 125, pp. 22–29
[6] Counihan J.: ‘Adiabatic atmospheric boundary layers: a review and analysis of data collected from the period 1880–1972’, Atmos. Environ., 1975, 5, pp. 871–905
[7] Justus C.C.: ‘Winds and wind system performance’ (Franklin Institute Press, Philadelphia, PA, 1978)
[8] Spera D.A.: ‘Wind turbine technology: fundamental concepts of wind turbine engineering’ (ASME Press, New York, 1994)
[9] Irwin J.S.: ‘A theoretical variation of the wind profile power exponent as a function of surface roughness length and stability’, Atmos. Environ., 1979, 13, pp. 191–194
[10] Giovanni G., Sauro S.: ‘Methods to extrapolate wind resource to the turbine hub height based on power law: a 1 h wind speed vs. Weibull distribution extrapolation comparison’, Renew. Energy, 2012, 43, pp. 183–200
[11] Ven den Berg G.P.: ‘Wind turbine power and sound in relation to atmospheric stability’, Wind Energy, 2008, 11, pp. 151–169
[12] Rehman S., Al-Abbadi N.W.: ‘Wind shear coefficient, turbulence intensity and wind power potential assessment for Dhulom, Saudi Arabia’, Renew. Energy, 2008, 33, pp. 2653–2660
[13] Argyle P., Watson S.J.: ‘Assessing the dependence of surface layer atmospheric stability on measurement height at offshore locations’, J. Wind Eng. Ind. Aerodyn., 2014, 131, pp. 88–99
[14] Sumner J., Masson C.: ‘Influence of atmospheric stability on wind turbine power performance curves’, J. Solar Energy Eng., 2006, 128, pp. 531–538
[15] Bratton D.C., Womeldorff C.A.: ‘The wind shear exponent: comparing measured against simulated values and analyzing the phenomena that affect the wind shear’. ASME 2011 Fifth Int. Conf. on energy sustainability, Washington, DC, USA, 7–10 August 2011
[16] Wang Y.H., Chen H.H., Guo L.X.: ‘Effects of atmospheric stability and wind fetch on microwave sea echoes’, IEEE Trans. Geosci. Remote Sens., 2014, 52, pp. 929–935
[17] Li F.Y., Zhang H.S., Chen J.Y.: ‘Progress of research on turbulence energy exchange of boundary layer’, J. Meteorol. Sci. Technol., 2004, 32, pp. 305–310
[18] Bowen A.J.: ‘Modelling of strong wind flows over complex terrain at small geometric scales’, J. Wind Eng. Ind. Aerodyn., 2003, 91, pp. 1859–1871
[19] Tse K.T., Li S.W., Chan P.W., et al.: ‘Wind profile observations in tropical cyclone events using wind-profilers and Doppler SODARs’, J. Wind Eng. Ind. Aerodyn., 2013, 115, pp. 93–103
[20] Poje D., Cividini B.: ‘Assessment of wind energy potential in Croatia’, Sol. Energy, 1998, 41, pp. 543–554
[21] Monin A.S., Obukhov M.A.: ‘Dimensionless characteristics of turbulence in the surface layer’, Akad. Nauk SSSR Geofiz. Inst., 1954, 14, pp. 228–230
[22] Hellman G.: ‘Uber die bewegung der luft in den unterstenschichten der atmosphere’ (Vieweg, Germany, 1915)
[23] Abbas M., Belhadj J.: ‘Development of a methodology for wind energy estimation and wind park design’, J. Renew. Sust. Energy, 2014, 6, pp. 348–357
[24] Panofsky H.A., Dutton J.A.: ‘Atmospheric turbulence’ (Wiley-Interscience, New York, 1984)
[25] Kubik M.L., Brayshaw D.J., Coker P.J., et al.: ‘Exploring the role of reanalysis data in simulating regional wind generation variability’, Renew. Energy, 2013, 57, pp. 558–561
[26] Yan J., Liu Y.Q., Han S., et al.: ‘Wind power grouping forecasts and its uncertainty analysis using optimized relevance vector machine’, Renew. Sust. Energy Rev., 2013, 27, pp. 613–621