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The Suitability of European Designed Wind Turbines for the East Asian Market

G. R. D. Brown, R. J. Barthelmie* and Hyun-Goo Kim**

SgurrEnergy, 225 Bath Street, Glasgow, G2 4GZ, UK
**Department of Atmospheric Science, Indiana University, Bloomington, IN 47405-7000, USA*
***Institute of Energy Research, Daejeon 305-343, Korea*

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Abstract

A first step review is completed on the suitability of European designed wind turbines in an East Asia climate. Six parameters are chosen for detailed analysis of proper meteorological measures from flat, hilly, forested, coastal and offshore sites in West Europe and East Asia: mean wind speed, 10 minute mean wind speed distribution, turbulence intensity, wind shear, 3 second extreme wind speed and 10 minute direction change. All six parameters are assessed with a view for contrast with the wind turbine design standard IEC61400. The diurnal and seasonal variation, average and extreme values of each parameter are calculated where appropriate. Industry standard software and analysis techniques have been employed to assess the applicability of existing wind turbine design standards and design guidelines for the East Asian market.

Key Words : Wind resource, Wind turbine, Asia

1. Introduction

The wind energy market is expanding rapidly. This growth is expected to continue as nation states seek to secure energy supplies and mitigate the threat of global warming. The traditional development area, Western Europe, is no longer the only area of significant expansion. In 2006 South and East Asia increased its installed capacity by 56% to 8,963 MW and a further increase of 210% by 2011 is forecast[1]. The majority of Wind Turbines Generator Systems (WTGS) are developed in Europe. They are depe. Theand commissioned to show best performance under ped in Eumeteorological conditions. Wind systems and c to shsveloped in and East Asia have many differences; for instance, the typical c to sology in South East Asia is Monsoon and Typhoon events in summertime. ped in Euy are depe. Tho y not expected to show the same best performance ace,ast Asia ; for. To improvn and develop WTGS load design for ,ast Asia ; for, the differences in meteorology between Europe and East Asia are identified with proper meteorological measurement and compared against current design guidelines and standards. The purpose of this paper is to review existing design standards and guidelines, to establish parameters and characterize WTGS load climates. Other operational conditions such as seasonal and diurnal climatic variation are also considered in order to improve and develop the general operations of WTGS.

2. Analysis Methods

2.1. Meteorological Parameter Selection

International Standard IEC 61400-1:2005[2] deals with safety philosophy, quality assurance and engineering integrity, and specifies requirements for the safety of WTGS, including design installation, maintenance and operation under specified environmental conditions.

Corresponding Author : G. R. D. Brown, SgurrEnergy, 225 Bath Street, Glasgow, G2 4GZ, UK
Phone: +44-141-227-1700
E-mail: gareth.brown@sgurrenergy.com

IEC61400 provides classifications of WTGS based on site wind speed and turbulence intensity (TI) along with assumptions and relationships regarding wind shear, extreme wind speed and wind speed distribution.

The Guidelines for Design of Wind Turbines[3] have been developed through the compiling of recent knowledge and standard practices used in the design and construction of WTGS. The guidelines contain information on all aspects of WTGS design from the original concept through to loading and environmental considerations. The guidelines repeat parts of IEC61400 and additionally provide transformations to converting hourly meteorological data into 10 minute data allowing a broader range of data sets to be used if required.

These two documents were used to select six meteorology parameters for comparisons between sites in Europe and East Asia: annual mean wind speed, 10 minute mean wind speed Weibull/Rayleigh distribution, TI, extreme one year and 50 year, 3s gust wind speed, wind shear profile and direction variability.

2.2. Site Selection

Characterizing and comparing climates requires high quality meteorological measurements. Four organizations agreed to release data for analysis including the Korea Institute of Energy Research. All datasets available for analysis are from West Europe, North China and South Korea as list in Table 1. Datasets are selected for their suitability in assessing the six parameters given above. At least one year of seasonally balanced wind speed, direction and standard deviation measurements at two heights are required. 10 minute data and maximum 3 second gust for each wind speed datum are preferable.

For comparison between regions it is required that local conditions of analysed sites are of comparable terrain and topology (i.e. flat, hilly, forested, coastal and offshore), height and altitude. Sites 11~14 are located at high altitude (~1,000 m). All of the data are checked and screened for anomalies. The datasets available cover various period lengths, between 1999~2007, in both West Europe and East Asia.

Figs. 1 and 2 present the monthly variation of wind speed at the selected West Europe and East Asia sites.

Table 1. Datasets for analysis

	Site	Terrain	Year of Balanced Data	Anemometer Heights
Europe	1	Flat	0.94	50/10 m
	2	Hilly	1.39	30/20 m
	3	Coastal/Flat	2.30	35/25 m
	4	Forested	2.15	30/40 m
	5	Offshore	1.01	35/13 m
	6	Coastal/Flat	2.92	30/40 m
	7	Hilly	1.34	30/20 m
East Asia	8	Coastal/Hilly	1.85	30/15 m
	9	Coastal/Flat	1.99	30/15 m
	10	Forested	1.10	30/15 m
	11	Flat	0.98	50/30 m
	12	Flat	0.99	50/30 m
	13	Hilly	0.98	50/30 m
	14	Hilly	0.98	50/30 m

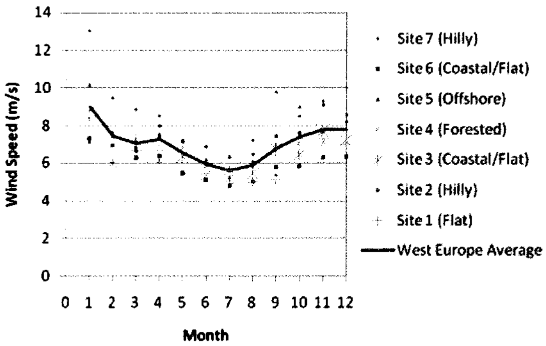

Fig. 1. West Europe mean monthly wind speeds.

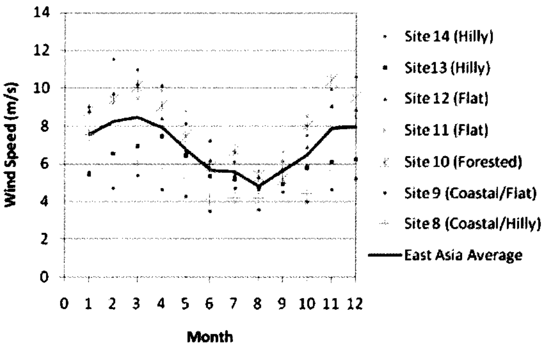

Fig. 2. East Asia mean monthly wind speeds.

There is a similar seasonal variation pattern in both West Europe and East Asia. Both regions show two seasons, high wind speed (winter) and low wind speed (summer). The European winter and summer periods correspond to the equinox dates 21st March and 21st September. However in East Asian sites, winter and summer periods are approximately one month out of sync with Europe, May 1st and November 1st.

West Europe sites 2~7 and East Asia sites 10~12 contain at least one year of seasonally balanced 10 minute wind speed, direction, standard deviation and 3s gust data. East Asia sites 8-9 have equivalent hourly measurements without 3s gust data. West Europe Site 1 is missing 3s gust data, but has all other required 10 minute data. The European and Asian sites are located within a 650 km^2 and 1800 km^2 area respectively. Sites 11-14 are located at high altitude (~1000 m).

The 30 metre height is the principal anemometer height used for analysis here. Although significantly below modern WTGS hub height, it enables a fair comparison of the wind regime between regions. A secondary anemometer (20 m) is selected for wind shear analysis. If these heights are unavailable, comparable alternative anemometers are used. No offshore data are available for analysis in East Asia.

3. Results and Discussion

Six parameters are assessed in Sections 4.1 ~ 4.6 to characterize wind turbine load climates in Europe and East Asia and to review the suitability of the design standard IEC61400 and Guidelines for Design of Wind Turbines for wind turbine design in East Asia. The analysis contains large uncertainty due to the short term data sets, lack of long term corrections and limited site information. Transformations specified in the design guidelines have not been considered, as their application is found to be poor. Analysis in Sections 4.3 ~ 4.6 is completed for wind speeds > 4 m/s.

3.1. Site Mean Wind Speed

The long term mean wind speed is one of the parameters specified by IEC61400 to classify a WTGS. Here, simple site long term corrections are completed using NCAR/NCEP reanalysis data and MCP (Measure Correlate Predict) procedure[4]. Figs. 3 and 4 show the short term measured and long term predicted wind speeds with each site's seasonal and diurnal variation.

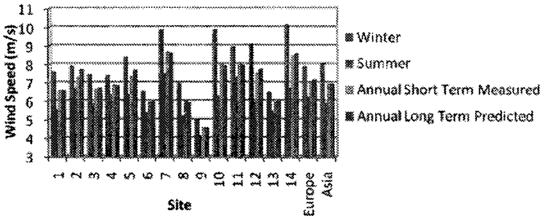

Fig. 3. Annual mean wind speeds.

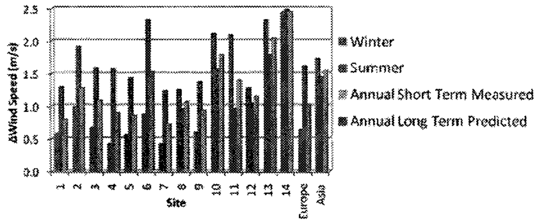

Fig. 4. Diurnal variation in wind speed.

The sites' short term measured and long term predicted wind speeds lie within existing IEC61400 wind turbine wind speed classes (<10 m/s). The analysis is completed below modern WTGS hub heights (~30 m). Applying the wind shear coefficients calculated in Section 4.4, two East Asia sites (11 and 14) approach (but do not exceed) the IEC61400 wind turbine wind speed classification limit of 10 m/s. Given the increasing hub heights of modern WTGS and the limited sites assessed, it is considered likely that current IEC61400 WTGS wind speed classifications do not allow the full utilisation of high resource sites.

Three East Asia sites exhibit seasonal variation significantly above the observed range in West Europe (>30%). East Asia sites exhibit diurnal variation typically higher than that at West Europe sites. The seasonal change in diurnal variation is less pronounced at the East Asian sites.

3.2. Site Wind Distribution and Energy Density

IEC61400 assumes that a site's 10 minute mean wind speeds are Rayleigh distributed. The wind turbine design guidelines state that a broader Weibull distribution is required to represent most 10 minute wind speed site data.

In this analysis 10 minute and hourly measured data from each site are fitted to a Weibull and Rayleigh distribution curve. The Weibull parameters are fitted using the wind industry standard software, Wind Atlas Analysis Application Observed Wind Climate program (WAsP OWC). The discrepancy between each curve and the measured data is calculated. Hourly and 10 minute calculated discrepancies are found to be similar at all sites. Only at two sites is the discrepancy difference greater than 1%, sites 4 and 12, both of which are sites.2.5%. Hourly data are used for analysis if 10 minute are not available.

Using the broader Weibull technique does not significantly outperform the Rayleigh fit in any region. Large distribution discrepancies (>10%) are observed at three of the East Asian sites (9, 10 and 12). The discrepancies appear to be due to an observed broad "non-Weibull" distribution. The broader distribution creates significant under representation of wind speeds greater than 10 m/s at East Asian sites.

Energy densities, seasonal variations of energy density and their standard deviations are comparable between regions.

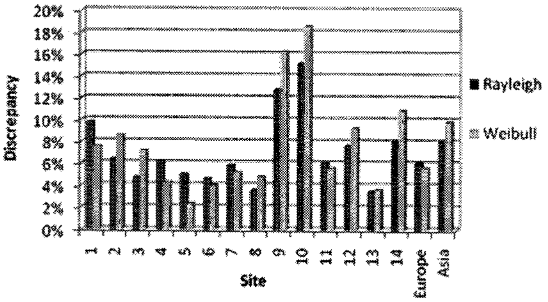

Fig. 5. Fitted distribution discrepancy.

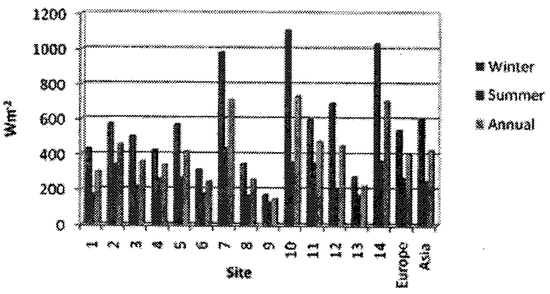

Fig. 6. Annual and seasonal energy density.

3.3. Site Turbulence Intensity

IEC61400 defines TI over a 10 minute period (TI10min). Three of the East Asia sites do not have 10 minute data available. TI over an han hanperiod (TI an ha) is consider(TI an site comparison and fannd ton-provide a conservative representation of TI10min, offset approximatehan+0.02 at all sites with suitable data an comparison. Figs. 7 and 8npresent each site's annual, seasonal and din nal TI an ha (8 m/s). An 8 m/s wind speed is chasen an ha) is c, hcont is the highest wind speed with suitable coverage at each site. The measurement h eacts (~30 m) are significantly below modern WTGS hub heights and are conservative values of the sites hub height ambient TIHourly.

The regions have similar average annual TIHourly (8 m/s) and there are limited seasonal variations. The diurnal variation of TIHourly (8 m/s) at the East Asia sites is significantly higher. A higher diurnal variation increases the frequency of high TIHourly events at the East Asia sites.

Fig. 9 shows the amount of time each site's TIHourly exceeds the IEC61400 class A charactersitic curve against the site's TIHourly (15 m/s). The as-

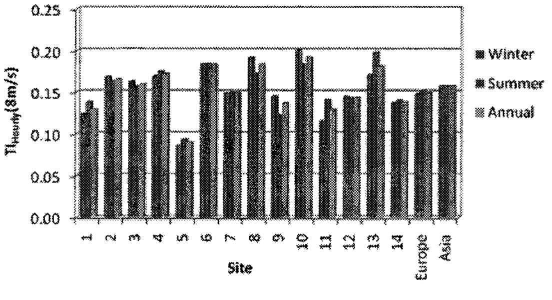

Fig. 7. Annual and seasonal TI Hourly (8 m/s).

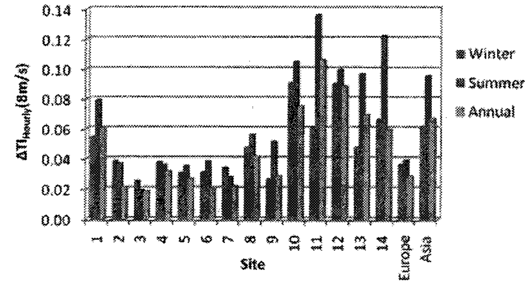

Fig. 8. TI Hourly (8 m/s) diurnal variation.

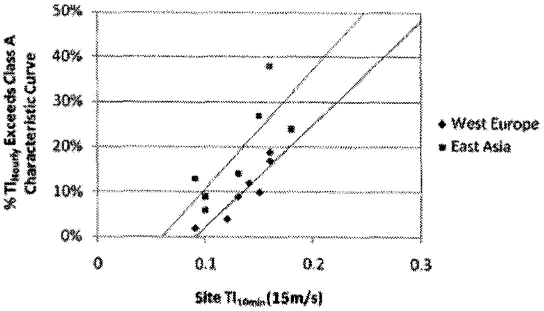

Fig. 9. Frequencies of High TI Hourly (8 m/s).

sessed sites of East Asia have significantly increased frequency of higher TIHourly events. This indicates a broader distribution and may affect the IEC61400 charateristic values of TI used for load calculations, which are based on the 90% quartile of the expected TI10min.

3.4. Site Wind Shear

IEC64100 assumes the wind shear power coefficient α to be 0.2. Figs. 10 and 11 present the seasonal and diurnal variation of the average α at each site. Two West Europe and East Asia sites exceed the 0.2 assumed value for the wind shear exponent. Further analysis reveals that the correlation between site wind speed and α is similar between regions and the frequency of higher values of α along with its seasonal and diurnal variation is also comparable.

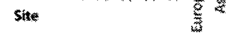

Fig. 10. Annual and seasonal wind profile exponent.

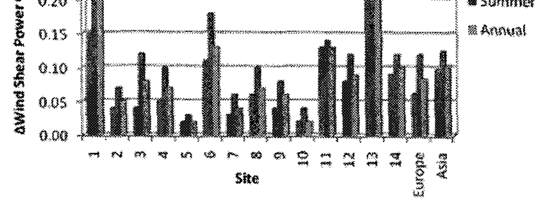

Fig. 11. Diurnal variation of wind profile exponent.

3.5. Site Extreme Wind Speed

The IEC61400 defines two extreme 3s gust wind speeds for each WTGS wind speed class, 50 year (Ve50) and 1 year (Ve1). Four sites do not have a year of seasonally balanced 3s gust data. IEC61400 specifies the use of gust factor analysis. The gust factor technique provides approximations of the maximum measured 3 second gust wind speed using the specified time period, wind speed and standard deviation measurements. The technique produces calculated maximum gust wind speed results to within ±6% of the measured and mean squared errors of less than 1 for all applicable sites.

IEC61400 specifies relationships for Ve50 and Ve1 from the site's long term mean wind speed (Vave). This relationship is applied to the measured Vave of each site in order to compare the measured maximum 3s gust wind speed against the IEC61400 assumed 1 year maximum, see Fig. 12. Where measured data are not available, the calculated gust factor data are used. Multiple methods exist to predict Ve50. The Prediction of Extreme Wind Speeds at Wind Energy Sites[5] provides a method of extrapolating the sites short term hourly Weibull distribution to an extreme 50 year distribution case. Relationships between measured site hourly and 3s gust wind speed wind are established and applied to the extreme wind speed distribution to

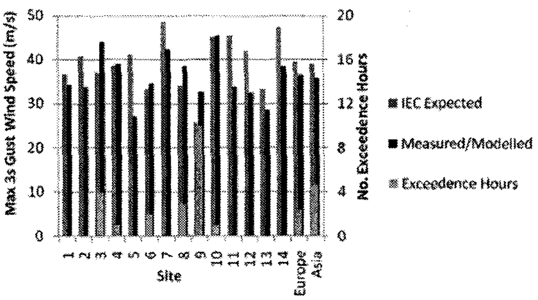

Fig. 12. IEC 1 year and measured maximum 3 second gust wind speed.

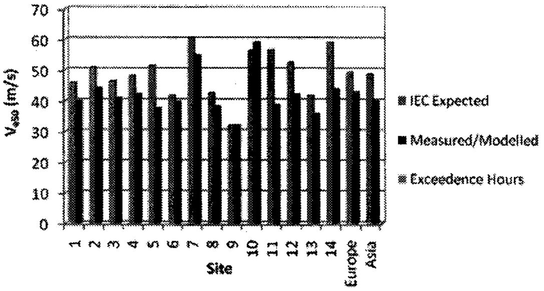

Fig. 13. 50 year IEC and predicted gust wind speed.

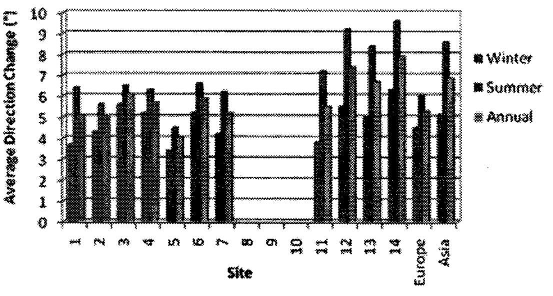

Fig. 14. Average 10 minute wind direction change.

give a prediction of Ve50.

Maximum measured and gust factor calculated short term 3s gust wind speeds are all within the limits of WTGS one year wind speed classes (<56 m/s). Exceedance of the IEC61400 Ve1 and Vave relationship only occurs in measured data when the observed period is greater than one year. Site 9, which has an observed non-Weibull distribution, has a large number of hourly records with gust wind speeds exceeding the IEC61400 assumed Ve1 maximum given it has a 2 year coverage period.

The IEC61400 relationship for Ve50 predicts a lower value than the gust factor correlation prediction at two sites in East Asia, both of which exhibit a broader non-Weibull short term wind speed distribution. All predictions of Ve50 and Ve1 lie within the standard WTGS wind speed classes, (<56 m/s).

4. Conclusions

The conclusions of this paper have been drawn as follows:

(1) Current standard IEC61400 WTGS wind speed classifications may not be suitable to maximize energy production at sites of very high wind resource in both European and Asian regions.

(2) Rayleigh and Weibull 10 minute mean wind speed distributions assumed by fitting IEC61400 are not suitable to define "broader" wind speed distributions in East Asia. In particular both fitted distributions significantly under estimate the proportion of higher wind speeds (>10 m/s) at these sites.

(3) Annual and seasonal energy densities and their standard deviations are comparable between regions.

(4) Diurnal variation of TIHourly is significantly higher across the East Asia sites. The higher diurnal variation creates an increased frequency of high TIHourly events at an East Asia site compared to a West Europe site with equivalent average TIHourly values.

(5) The wind shear profiles, seasonal and diurnal variation are comparable between East Asia and West Europe.

(6) Site results indicate that IEC61400 relationships for Ve50 and Ve1 are not suitable for sites where the distribution is of broad non-Weibull type.

(7) East Asian sites show significantly higher annual and seasonal directional variability. This combination leads to very high variability in the summer months.

(8) Further analysis should be completed on European data covering a larger geographical area and on additional 10 minute datasets in East Asia to confirm any initial observations and conclusions.

Acknowledgements

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