Whale, J., McHenry, M.P. and Malla, A. (2013) *Scheduling and conducting power performance testing of a small wind turbine.* Renewable Energy, 55 . pp. 55-61.

Scheduling and conducting power performance testing of a small wind turbine

J. Whale[ab]*, M. P. McHenry[a] and A. Malla[a]

[a]*School of Engineering and Energy, Murdoch University,* [b]**National Small Wind Turbine Centre, Murdoch University, 90 South Street, Murdoch, Western Australia, 6150, Australia.* J.Whale@murdoch.edu.au *+61 8 9360 7235, +61 8 9360 2102*

ABSTRACT

The global growth in small wind turbine (SWT) markets and in the number of SWT manufacturers has brought about an urgent need for more rigorous testing of SWTs in order to ensure safety, reliability and performance. This work presents modelling of the wind resource at the Australian National Small Wind Turbine Centre (NSWTC) test site to give insight into the scope and scheduling of power performance tests, and assess testing completion requirements for national and international SWT performance standards. Wind modelling of the long-term wind resource at the site was used to guide the NSWTC testing program and develop a tool to provide recommendations regarding suitable months for testing particular turbines. The predictions from the tool are compared to the results of testing a SOMA 1000 small wind turbine. The results indicate that current testing standards need to specify more than 10 minutes worth of data in each bin in order to reduce uncertainty errors in power curves, particularly at higher wind speeds and during furling and unfurling of the turbine. Furthermore, this work supports observations that there are often notable discrepancies between published SWT manufacturer power curves and test results at high wind speeds.

***Keywords**: small wind turbines; performance standards; power curves; power performance testing; wind resource assessment.*

1. Introduction

The global market for small wind turbines (SWTs) has shown tremendous growth in recent years, particularly in the US and UK [1, 2]. The US market accounts for around 50% of the global market, and in 2009 surpassed the milestone of 100 MW of small wind installed capacity [3]. In the UK, the year 2010 saw a 65% increase in the annual installations of SWTs, establishing a new national record in SWT deployment [4]. Paralleling installed capacity, the growth in the number of global manufacturers of SWTs has been phenomenal, rising from an estimated 69 manufacturers in 2006, to approximately 250 in 2009 [3, 5]. This expansion has a number of observers expressing some concern that not all available models of SWTs are reliable or safe [1, 6-8]. The characteristic of the power curve is vital influencing the power production and associated error [9], and there is a surge of renewed interest in the determination of SWT power curves, rated wind speeds, and reliability (etc.), [10]. Historically, SWT manufacturers have not had to undergo the same stringent certification procedures as large wind turbine manufacturers, and SWT test data is often provided only by manufacturers without independent verification. Gipe [11], Bowen *et al*. [12], and Li *et al.* [13] have shown that there are often notable discrepancies between measured power curves and those supplied by the manufacturer.

On a national level, the American and British Wind Energy Associations have both produced safety and performance standards for SWTs [14, 15]. The US and the UK have established frameworks for certification of SWTs, through the Small Wind Certification Council (SWCC) and the Microgeneration Certification Scheme (MCS), respectively

[16]. This movement was elevated to an international level with the formation of a Small Wind Turbine Liaison Program jointly co-ordinated by the International Electrotechnical Commission (IEC) and the International Energy Agency (IEA). The program has led to a complete revision of IEC61400-2 [17], the international standard for small wind turbines, and the publication of recommended practices on testing of SWTs [18]. A small number of researchers have published informal testing results of SWTs (e.g. Encraft [19], Gipe [20]), while others are now testing to the newly formed standards and introducing much-needed rigor (e.g. Bowen *et al*. [21]). Rigorous testing consists of design data testing, power and acoustic performance testing, and safety and duration testing. The SWCC advise that "…testing and reporting may take as much as 1 or 2 years to complete" [22].

The National Small Wind Turbine Centre (NSWTC) was established in August 2008 and is funded by the Australian Federal Government's Department of Climate Change and Energy Efficiency. The NSWTC's primary aim is to test and label turbines in the range 1 kW – 5 kW, and assist the local development of the SWT industry in Australia and abroad [1]. 18 potential sites were initially identified for establishing the NSWTC's test facility, with five sites short-listed and ranked against wind resource, security, area available, tenure, lease costs, accessibility, and on-site resource criteria. As the top-ranked wind resource site was unavailable due to planned construction in the area, the short-listed site in the suburb of Henderson in Perth was selected as the NSWTC test site with an on-site wind monitoring station at 10 m a.g.l. The NSWTC are active participants in the IEC/IEA Small Wind Turbine Liaison Program and use the Henderson site to assess SWTs in accordance with international standards for power and acoustic performance as well as safety and duration testing. This work describes results of only power performance testing of a selected SWT, the SOMA 1000, and also includes discussion on the results of duration testing The NSWTC's planned testing program gave rise to a number of research questions for the Henderson site including:

- What is the long-term wind resource at the site?
- What are the most suitable times of the year for SWT power performance testing?
- What size of turbines can be tested on site?

This work describes the modelling of the wind resource at the NSWTC test site to give insight into the scope and scheduling of power performance testing at the site. The objectives were to: 1) Review typical SWT performance characteristics; 2) Review SWT power performance standards to assess test completion requirements; 3) Model the wind regime at the site; 4) Predict the type of SWTs that can be tested, the optimal time of year for testing and the associated length for the test, and; 5) Compare predictions with actual test data from a grid-connected SOMA 1000 at the NSWTC Henderson site.

2. Material and methods

2.1. Revision of SWTs and SWT standards

A SWT is defined in accordance with the IEC61400-2 standard as a wind turbine with a swept area less than 200 m^2. The power capacity of such a machine is typically less than 50 kW. The performance specifications of forty SWTs ranging in capacity from 1 kW to 50 kW were compiled. This data yielded an estimate of 3 m s^{-1} as a typical cut-in wind speed of a SWT. Many SWTs do not cut-out as such and are designed to operate in wind speeds up to around 60-70 m s^{-1}. Many horizontal-axis SWTs will furl to protect themselves at around 16-17 m s^{-1}. The hub-heights of the forty SWTs ranged from 5 m (e.g. a roof-mounted 6 kW Quiet Revolution turbine) to 62 m (e.g. a 30 kW Pitchwind machine). The data yielded an average height of 20 m, although 18 m is more typical of tower heights offered by manufacturers as towers are often comprised of 6 m sections).

The international standard relevant to power performance testing of wind turbines is IEC61400-12-1 [23]. Annex H deals specifically with the power performance testing of SWTs, and states that 1-minute averaged power and wind speed data are to be logged and binned to form the wind turbine power performance curve. The wind speed data are measured at a height within ±2.5% of the turbine hub height and, for grid-connected SWTs, the A.C. turbine power data are measured at the connection to the load (after the inverter). For the binning of data, wind speed bins are created with width 0.5 m s^{-1}, centred on integer multiples of 0.5 m s^{-1}.

In regards to completion of power performance testing, section (n) of Annex H of IEC61400-12-1 [23] states:

> " …the database shall be considered complete when it has met the following criteria:
>
> 1) each wind speed bin between 1m/s below cut-in and 14m/s shall contain a minimum of 10 min of sampled data,
> 2) the total database contains at least 60 hours of data with the small wind turbine within the wind speed range
> 3) In the case of furling turbines, the database should include completed wind speed bins characterizing performance when the turbine is furled"

The AWEA and BWEA Safety and Performance Standards [14, 15] have similar criteria to IEC61400-12-1 in terms of completion of power performance testing, with the exception of point 3), which is replaced by: "The database shall include 10 minutes of data for all wind speeds at least 5 m/s beyond the lowest wind speed at which power is within 95% of maximum power (or when sustained output is attained)". Averaging at 1-minute intervals, 10 minutes of data then requires 10 readings. In this paper a bin is said to 'filled' when it contains 10 readings.

The output of the power performance tests via all the standards referred to above is a turbine power curve; electrical power output from the SWT (e.g. to the grid) correlated with wind speed. In all the above standards, the Annual Energy Production (AEP) of the turbine at a range of hypothetical sites is derived using the convolution of the turbine power curve and the Rayleigh probability density function, which provides a reference wind speed frequency distribution at a site. Many SWTs do not cease production in high winds, and for these SWTs IEC61400-2 requires calculation of an AEP using an extrapolated power curve from the highest filled wind speed bin up to 25 m s^{-1}. The extrapolation assumes a constant value over this range of wind speeds equal to the power value from the highest filled wind speed bin.

Duration testing is performed concurrently with power performance testing, with the completion of both tests reliant of collecting enough high wind speed data.

IEC 61400-2 states [17]:

> "The wind turbine will have passed the duration test when it has achieved:
>
> - reliable operation during the test period;
> - at least 6 months of operation;
> - at least 2500 h of power production in winds of any velocity
> - at least 250 h of power production in winds of 1.2 V_{ave} and above; and
> - at least 25 h of power production in winds of 1.8 V_{ave} and above."

The parameter V_{ave} is associated with the Class of SWT as shown in Table 1, adapted from the standard [17]. The results of the duration testing then define the Class of SWT. A longer period of testing captures more data at high wind speeds and can result in a change of class of SWT.

The AWEA/BWEA Performance and Safety Standards [14, 15] have similar requirements to IEC61400-2 for duration testing but in addition specify "... the test must include at least 25 hours in wind speeds of 15m/s (33.6 mph) and above". Compliance with this criterion effectively sets the design classification of the SWT to Class I or II.

Table 1: Velocity-based basic parameters for SWT Classes (adapted from IEC61400-2)

SWT Class	**I**	**II**	**III**	**IV**	**S**
V_{ref} (m s^{-1})	50	42.5	37.5	30	**Values to be specified by the designer**
V_{ave} (m s^{-1})	10	8.5	7.5	6	

where

- **the values apply at hub height, and**
- **V_{ref} is a reference wind speed for the site and is typical of the average maximum wind speed experienced by the SWT**
- **V_{ave} is the average wind speed experienced by the SWT**

2.2. Wind resource assessment

Over the period September – December 2009, preliminary monitoring of the wind at 10 m a.g.l. at the Henderson test site was carried out using a Davis 7911 instrument with wind speed and wind direction sensors, calibrated in a wind tunnel. WAsP 9.0 was used to produce a longer-term prediction of the wind resource at the NSWTC site, involving the creation of a wind atlas, as a site-independent characterisation of the local wind climate, by using long-term reference data from a nearby site along with descriptions of terrain, obstacles and roughness at both the reference site and the test site [24, 25]. The WAsP model was run using half-hourly wind data collected during September – December 2009 from Jandakot Airport, which has an aerial distance of 10.6 km from the NSWTC test site. The data recorded during the preliminary monitoring at the Henderson site were used to validate the WAsP model, which was subsequently run using individual monthly files from 10 years of half-hourly wind data from 2000 to 2009 measured at 10 m a.g.l at Jandakot Airport. The wind atlas created by the model generated monthly Weibull wind speed distributions at various roughness lengths and various heights. In order to predict the wind climate that a SWT would experience at the test site, the variation in roughness in a 10 km radius around the site was determined by identifying with descriptions of terrain from the European Wind Atlas [26]. The wind climate was predicted at 18 m a.g.l., since this was a common height for SWTs as previously mentioned. The predicted shape parameter (k) and scale parameter (A) of the Weibull distribution from WAsP were used to calculate the probability density function, $f(v)$, for the respective mean speed (v) at each bin interval midpoint using Eq. 1. Wind speed bins were established using the IEC61400-12-1 standard convention, and a spreadsheet-based analysis tool was created to predict monthly wind speed distributions at the test site.

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \exp\left(-\left(\frac{v}{A}\right)^{k}\right) \qquad \text{Eq. 1}$$

2.3. Comparison of power performance and modelled data

Power performance testing of a SOMA 1000 (1 kW) - a horizontal-axis, 2-bladed, furling SWT - commenced in April 2010 at the NSWTC site. From the power curve published by the manufacturer, the rated instantaneous power of the SOMA turbine is 1000 W at a rated wind speed of 10 m s^{-1} with a peak output of 1200 W at 15 m s^{-1} [27]. The SOMA turbine was mounted at a hub-height of 19.5 m a.g.l. and 1-minute averaged power values were logged and correlated with wind speed measurements from a calibrated Vaisala WAA151 anemometer on a 18m meteorological mast. The IEC61400-12-1 standard was used in power performance testing of the SOMA turbine in order to comply with the NSWTC’s activities under the IEA Task 27 program. The turbine monitoring was used to provide real data for comparison with the predictions from the spreadsheet analysis tool. In particular, wind speed bins were checked for completion in accordance with the criteria from the standards as set out in Section 2.1.

3. Results

3.1. Wind resource

The predicted seasonal wind speed distributions were derived from the database of WAsP predictions of monthly wind speed distributions and are presented in Fig. 1. The Summer and Spring distributions were skewed more to the right, and as a result are better aligned with the typical wind speed range of a small wind turbine. The strong south-westerly sea breezes that occur over late Spring and Summer are responsible for the higher mean wind speeds during these seasons. The tails of the distributions are important in terms of likelihood of completion of higher wind speed bins. Fig. 2 focuses on the tails of the distributions and indicates that it is more likely to complete higher wind speed bins in Winter and Spring. The gusts from occasional storms and squalls that occur in Winter and early Spring are responsible for the higher maximum wind speeds during these seasons.

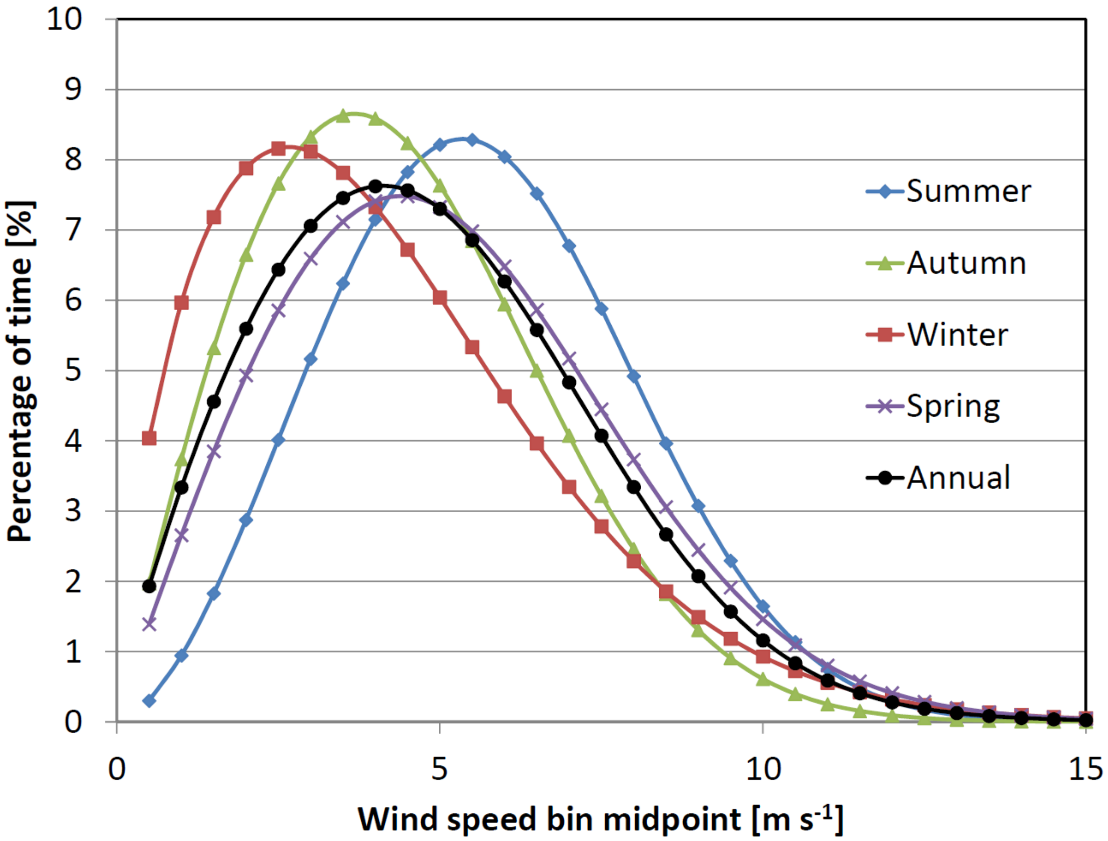

Fig. 1. Predictions of seasonal wind speed distributions at the NSWTC test site relative to the annual average. (Note Summer = Dec, Jan, Feb; Autumn = Mar, Apr, May; Winter = Jun, Jul, Aug; Spring = Sep, Oct, Nov).

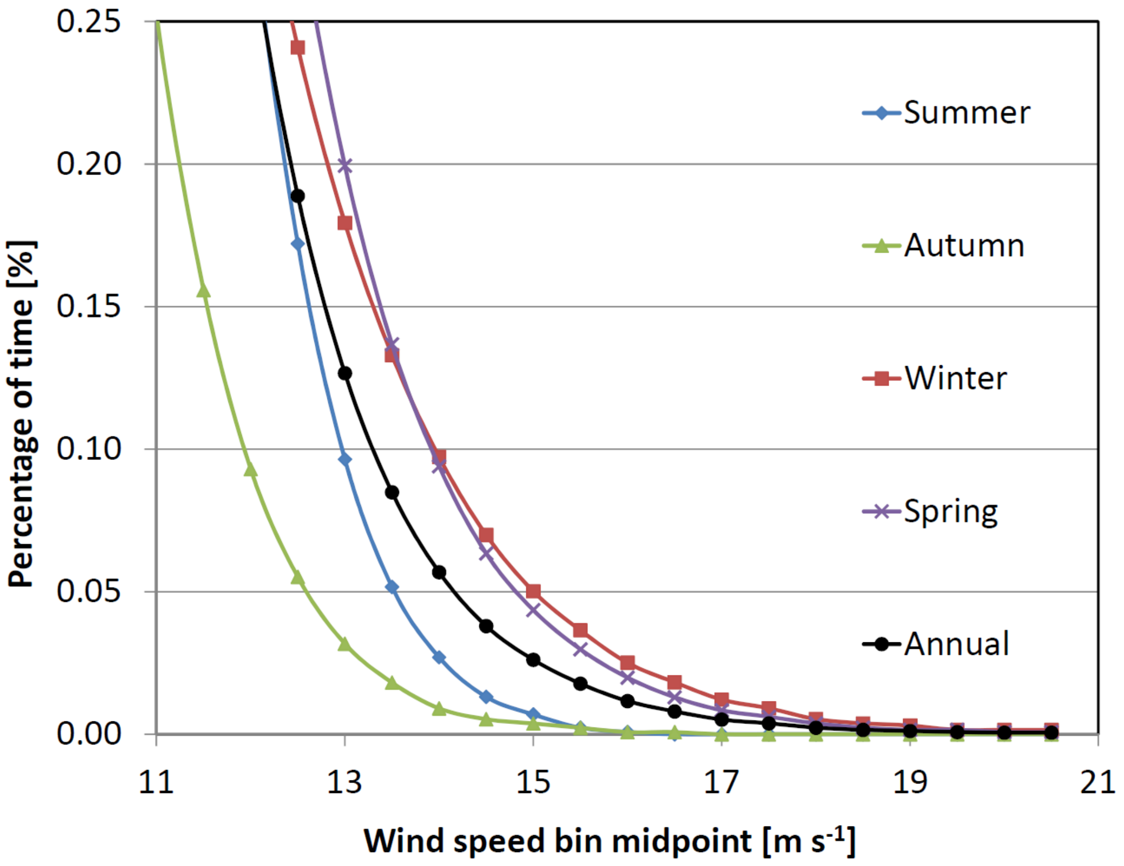

Fig. 2. Tails of the predicted seasonal wind speed distributions at the site relative to the annual average.

3.2 Scheduling of power performance testing

Table 2 presents the results of the power curve completion criteria given by the IEA, AWEA and BWEA standards mentioned in Section 2.1. The WAsP-predicted mean wind speeds shown are consistent with the skewed profiles from Fig. 1 and Fig. 2. Despite higher mean wind speeds in late Spring and Summer, the best time to be testing is in winter and early spring. Table 2 shows all months meet the criteria of more than 60 hours of SWT operation. In addition, January as well as June to December meet the criteria of completing wind speed bins 2 -14 m s^{-1}. The key criterion is the maximum completed bin. If the turbine is a furling HAWT, these results show that in order to comply with point 3) of the IEC standard, September must be included in the testing time schedule, and completion of testing is then reliant on the turbine being completely furled at 17 m s^{-1}. If testing to the AWEA and BWEA standards, the maximum completed bin places restrictions on the type of turbine that can be tested. From point 3) of these standards as stated above, the rated wind speed for the turbine can be estimated as 5 m s^{-1} below the maximum completed bin. The final row in Table 2 shows the estimated rated wind speeds for the eligible months. Thus, only turbines with rated wind speeds of at most 12 m s^{-1} can be tested at the NSWTC's Henderson test site in order to comply with AWEA and BWEA standards, and again completion of power testing would rely on September being included in the testing time schedule. Nonetheless, despite these issues for some turbines, approximately 70% of the forty SWTs reviewed by the authors exhibited rated wind speeds of 12 m s^{-1} or less.

Table 1 Results of cross-checking WAsP monthly distributions versus IEC, AWEA and BWEA standards' criteria

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean wind speed (m s^{-1})	5.7	5.6	5.1	4.3	3.9	4.1	4.3	4.3	4.9	5.0	5.6	5.8
2-14 m s^{-1} bins complete	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hours of data in range (h)	669	605	633	528	484	472	495	495	536	600	636	670
Max. completed bin (m s^{-1})	14	13.5	13	12.5	13.5	15	16.5	16.5	17	15	14	14
Rated wind speed estimate satisfying AWEA and BWEA	9	-	-	-	-	10	11.5	11.5	12	10	9	9

3.3 The power curve from SOMA 1000 turbine

Fig. 3 shows the measured power curves for the SOMA 1000, corrected to sea level air density 1.225 kg m^{-3}, that are deemed to satisfy the completion criteria in IEC61400-12-1. Two datasets have been plotted that satisfy the duration test for a Class III turbine and a

Class IV turbine, respectively, with SWT classes as defined in IEC61400-2. All data points were plotted (“database A” as per IEC61400-12-1), and uncertainty calculations were carried out based on ISO information publication “Guide to the expression of uncertainty in measurement”, and expressed as standard error bars [17]. Fig. 3 shows that uncertainty (represented by error bars) increases toward the end of the power curves due to the low number of points in the bins, and the lower the class, the more hours of testing in higher wind speeds are required. The SOMA 1000 was observed in the field to start furling at 15 m s^{-1}, and thus was assumed to satisfy the criteria for completion as per the IEC standard. Completing a power curve to Class IV took only 3 months (testing through September was not required in contrast to the prediction by the scheduling analysis), whereas completing a power curve to Class III took 16 months, and the reduction in uncertainty with longer testing is clearly shown in Fig 3. There is also an increase in the highest filled bin with longer testing, with the highest filled bin in the Class IV power curve of 17 m s^{-1}, compared to17.5 m s^{-1} for the Class III curve. The Class IV curve error bars increase notably from around 12 m s^{-1}, despite each bin having at least 10 readings. By contrast, after 16 months of testing these error bars have significantly reduced particularly towards the tail of the Class III curve. Testing of the SOMA 1000 continued beyond Class III completion to further reduce uncertainty in the tail of the power curve.

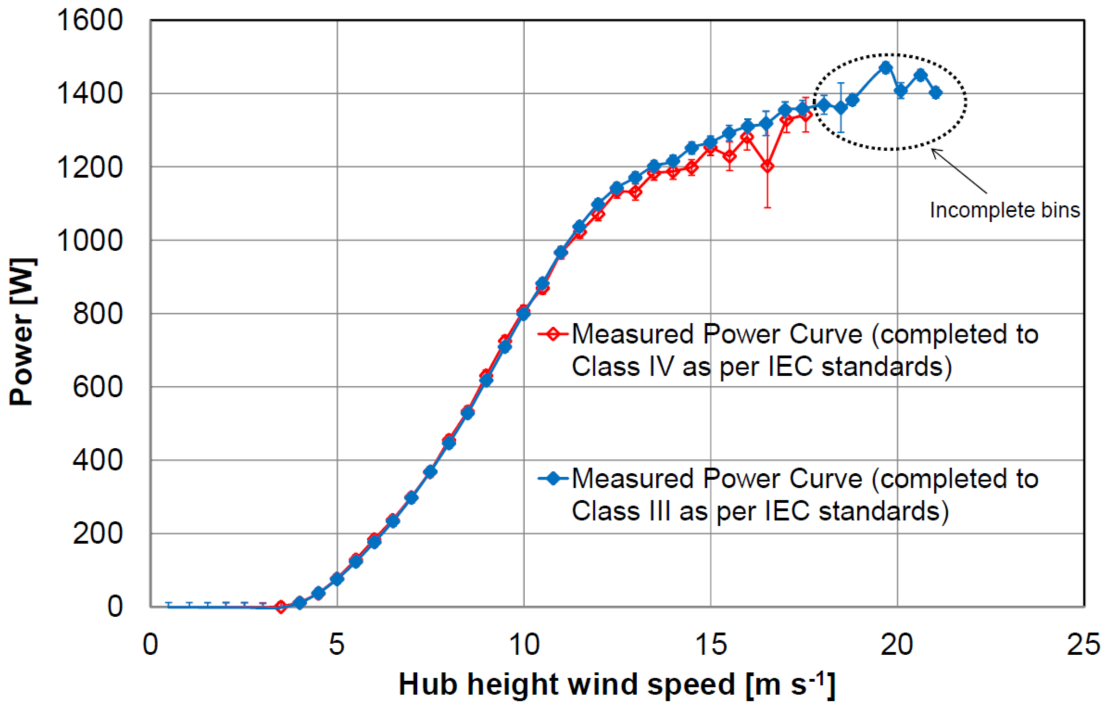

Fig. 3. Measured power curves for the SOMA 1000 for Class III and Class IV external conditions.

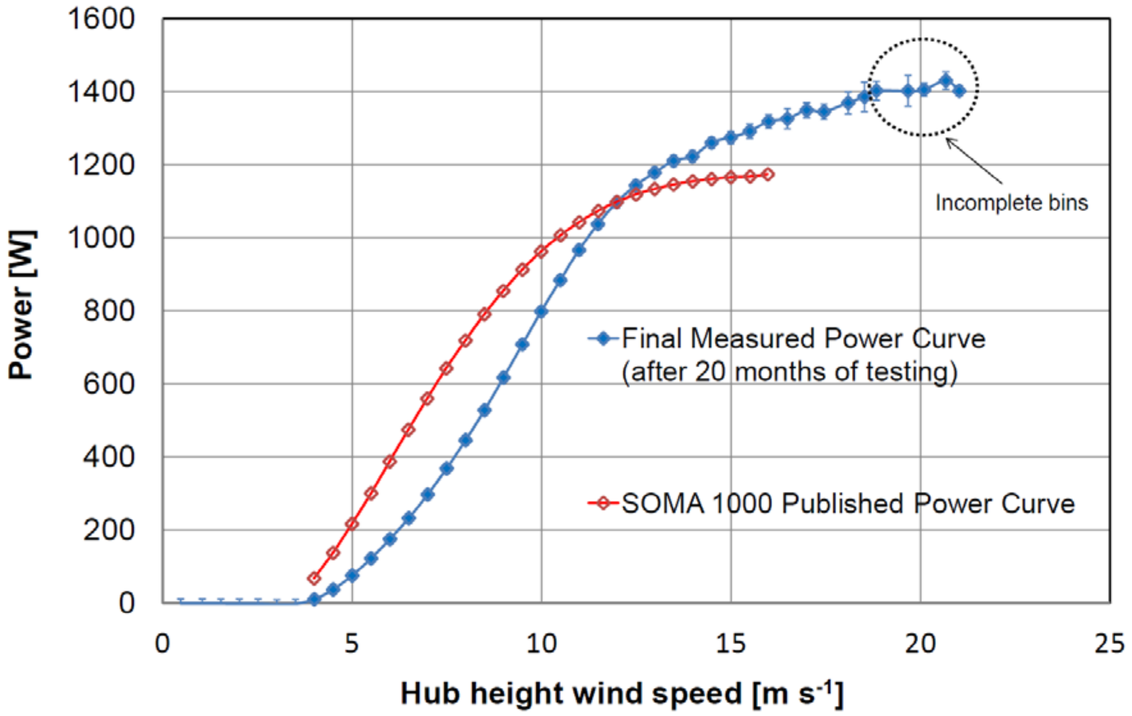

Fig. 4. Final measured power curve for the SOMA 1000 versus SOMA’s published power curve. Source of SOMA data: [27].

The latest measured power curve for the SOMA 1000 (after 20 months of testing) is shown in Fig. 4 and is contrasted against the manufacturer's published power curve. Comparison of the latest measured power curve with SOMAs published power curve show distinct differences. From the manufacturer's claim the turbine starts power limiting/protection behaviour at around 10 m s^{-1}, whereas the test results indicate this behaviour is delayed until around 12 m s^{-1}. Thus, below 12 m s^{-1}, the published power curve over-predicts performance, and above 12 m s^{-1}, the published power curve under-predicts performance. Based on completed wind speed bins, the measured power curves predict a peak power of approximately 1390 W at around 18.5 m s^{-1}, 190 W higher than the 1200 W peak power stated by the manufacturer. Several published works [11, 13, 20, 21, 28, 29] have shown that these kinds of discrepancies are common for SWTs, often due to various furling characteristics, and potentially a manufacturer testing in battery-charging mode rather than grid-connected mode which would clamp the generator voltage at a constant value, avoiding generator-inverter interactions [12]. Nonetheless, the IEA consumer labelling practices for SWTs recommends the use of Annual Energy Production (AEP) based on a site with a mean wind speed of 5 m s^{-1} in contrast to the use of rated power from power curves [18]. Fig. 5 compares the SOMA 1000 published manufacturer AEP and the extrapolated AEP curves based on 3-months as well as 20-months worth of measured power curve data s. The extrapolated AEP curves show good agreement with the published curve, and the calculated AEP at 5 m s^{-1} from the 3-month and 20-month power curves only vary from the manufacturer's curve by 5.96% and 4.65%, respectively. Fig. 5 shows a reduction in uncertainty with more data across the range of site wind speeds from 4 m s^{-1} to 11 m s^{-1}. The figure also suggests that for sites with greater annual mean wind speeds, the amount of testing time given to the turbine plays a more significant role in determining the values of extrapolated AEP calculated using the standard. This is to be expected since sites with higher mean wind speed give greater weighting to higher wind speed bins and these bins are associated with larger values of uncertainty since they contain fewer data points.

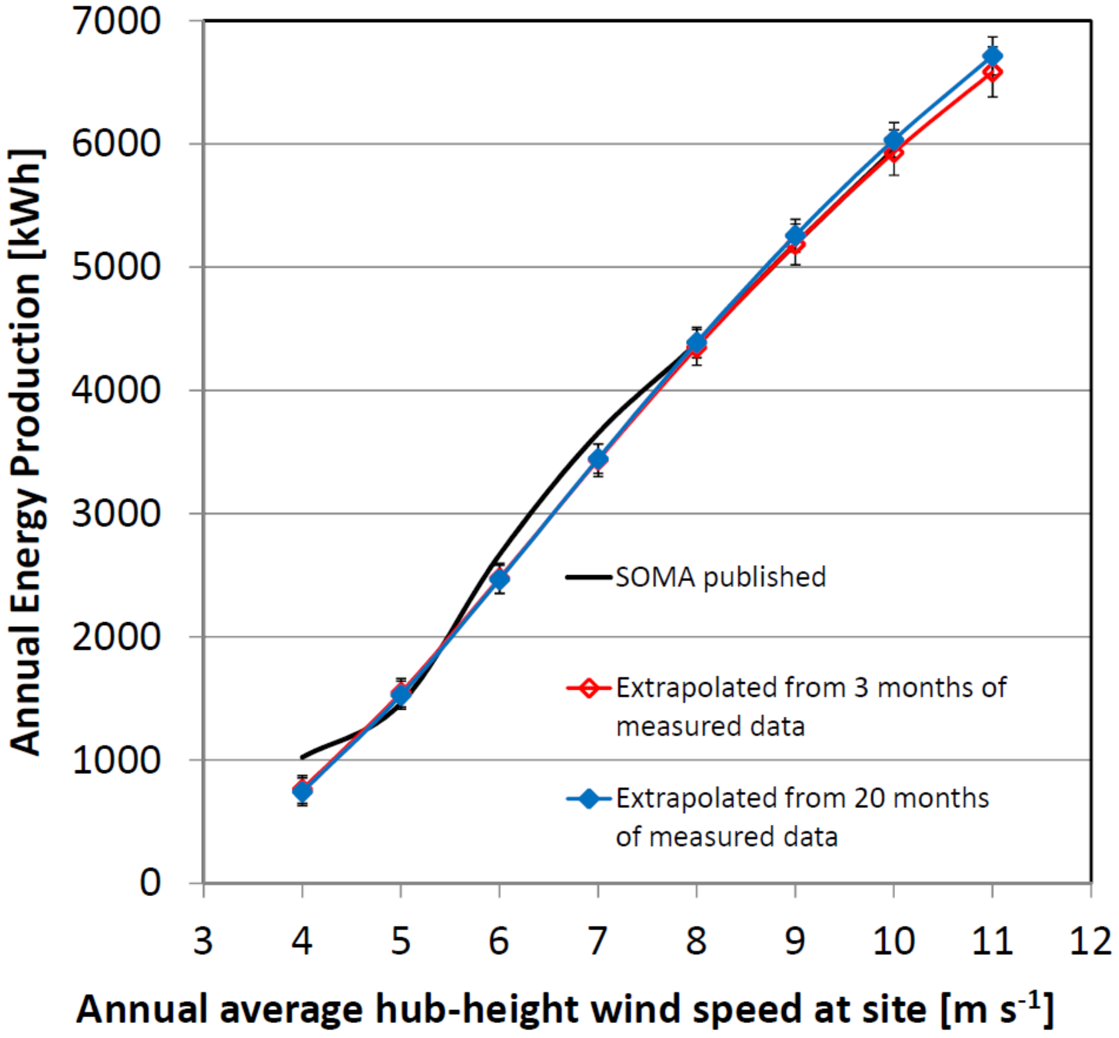

Fig. 5. Comparison of the published AEP values of the SOMA with extrapolated values based on measured test data. Source of SOMA data: [27].

4. Discussion

The research demonstrated that wind modelling can predict that Winter and Spring are the seasons at the NSWTC's Henderson test site that are most likely to complete the higher wind speeds bins on the power curve to meet the requirements of performance standards. The model also accurately predicted the highest completed wind speed bin in Class IV testing (17 m s^{-1} from both prediction and measurements). However, the model was a poor predictor of the length of time that the SOMA 1000 requires to fill the highest completed wind speed bins. The model predicted that the SWT test commencing on April 29th, would need 5 months of testing, whereas good winds during July meant Class IV testing required around half this time. These discrepancies are likely to be due to the known limitations of using WAsP and the Weibull function to model actual wind speed distributions [13, 30]. Fig. 6 shows the comparison of the WAsP predicted wind speed distribution to the wind speed distribution as measured over 20 month. The WAsP modelling predicted the mean wind speed at the site to within 1% of the measured value, although the shape and the scale parameters for the two curves have greater discrepancies. In particular the shape parameter from the data is approximately 8.5% higher than the WAsP prediction, leading to a peakier curve and suggesting that the WAsP model has under-predicted the turbulence levels at the site. The tails of the wind speed curves, which have a significant influence on the calculation of AEP, compare well. The primary limitations of using WAsP at the NSWTC are likely to be associated with the lack of detail in site topographical and land use maps. A difference of around 1.5 m between the model input height and the actual hub-height may have contributed to sources of error, but this is likely to be negligible. The 'goodness of fit' of the WAsP-produced Weibull distributions to measured data is likely to vary over the wind speed bins and improve towards the bins associated with the main body of the distribution due to the larger sets of observed wind data. In addition testing time in practice would be affected by issues such as turbine and monitoring system availability as well as removal of invalid wind data from measurement sectors that do not comply with the standard.

Although the SOMA 1000 has been observed in the field to begin furling at 15 m s^{-1}, some doubt remains as to whether the measurements are “...characterizing performance when the turbine is furled”, as per IEC61400-12-1 [23], and this clause requires further clarification. One would expect a completely furled turbine to experience a reduction in power output but beyond 15 m s^{-1} the measured SOMA 1000 power values continue to increase, although the decreased rate of power gain with wind speed does support the observation that the turbine is limiting power through furling to a degree. Ideally completing power curve bins up to 20 m s^{-1} would ensure that the furling behaviour is completely characterised, although this would involve a much longer period of testing at the Henderson test site.

The model assumed an ideal SWT power curve where the rated wind speed is the wind speed when the turbine reaches its maximum power. The rated wind speed for the SOMA 1000 SWT is 10 m s^{-1}, and this study presumed that the power curve test would be completed in accordance with the AWEA and BWEA standards once the 15 m s^{-1} bin was filled. However, as SWTs do not have ideal power curves, one can see that the SOMA 1000 power values continue to rise at wind speeds beyond 10 m s^{-1}. Whilst the published manufacturer data states that the SOMA 1000 maximum power (1200 W) is achieved at 15 m s^{-1}, this research demonstrates that around a 16% higher maximum power output can be achieved at approximately 18.5m s^{-1}. The reasons that SWTs have non-ideal power curves are partly due the relatively low accuracy of power control when compared to larger wind turbines that ensure that power values attained after the rated wind speed are either sustained or reduced. In addition, the SWT industry does not have the same stringent regulatory procedures of power curve testing and certification, allowing manufacturers to choose higher rated wind speeds to suit the market objectives of lower relative cost per kW [11].

The IEC standard was used with the SOMA in order to comply with the IEA Task 27 program, however, this research demonstrates that if the AWEA or BWEA standard were to be applied, and the maximum power can be confirmed to be in the order of 1390 W at 18.5 m s^{-1}, then it is likely that the test would only be completed once the 21 m s^{-1} bin (or higher) were filled. Although the Henderson test site has recorded 1-minute averaged wind speeds up to around 21 m s^{-1}, it would not be possible to complete power testing to AWEA/BWEA standards at this site (and many others) in a reasonable timeframe, a notable consideration for manufacturers [31].

In the area of duration tests, the AWEA/BWEA standards are also more stringent than the IEC standard. Even after 20 months of testing, the SWT was only exposed to just over 6 hours of wind speeds above 15 m s^{-1}, rather than the 25 hours required, and it would not be possible to complete the duration test to AWEA/BWEA standards in a reasonable timeframe for manufacturers. Figs. 3, 4, and 5 show that more testing time is needed to reduce the uncertainty in both power curve and AEP estimate. Testing time is expensive for the manufacturer and the question arises as to the value of increased testing time for SWT. The results of the AEP in Fig. 5 can be examined in an Australian context by estimating the effect that the difference in AEP would have in calculation of the number of Small-scale Technology Certificates (STCs), a tradeable commodity under an Australian Federal Government Scheme that provides financial incentives for investment in small-scale renewable energy. Upon installation of a small-scale renewable energy system (including SWTs), the consumer can claim a set number of STCs based on the amount of MWh of electricity generated by the system in megawatt hours over the course of its lifetime[1] (up to 15 years) [32]. STCs can be deemed in advance in lieu of future generation. For SWTs the maximum period for

---

[1] one STC equals one megawatt hour (MWh) of electricity generated

which STCs can be deemed in advance is 5 years. Many installations, including SWTs, are also eligible for Solar Credits, another Australian Federal Government Scheme that provides a rebate on some renewable energy technologies, including SWTs, by increasing the number of STCs that can be created for the SWT installation. The Solar Credits Scheme, however, is due to terminate in July 2013, so has not been taken into account in this analysis. Table 3 shows the greatest range in uncertainty in AEP with respect to testing time by taking, for each hypothetical site, the lower range of the extrapolated AEP after 3 months of testing and the upper range of the extrapolated AEP after 20 months of testing. For each set of results, the data is entered into the Small Generation Unit STC Calculator provided by the Clean Energy Regulator [33], to yield approximate numbers of STCs created by installation of the SOMA 1000 at each site. Table 3 shows that by increasing the length of testing from 3 months to 20 months, only an extra 1 or 2 STCs are predicted. Given a maximum price of AU$40 per certificate on the STC market at present [32], this suggests that, at least in the case of the studied SOMA that testing time will not have a significant influence on the energy production of the turbine. From Figs. 3 and 4, however, testing time has a significant influence on the shape of the power curve in high wind speeds, the part of the curve where the wind turbine is controlling and limiting power harnessed from the wind. The turbine power curve is programmed into a controller/inverter, and it is likely that a power curve produced from insufficient testing time will lead to less-than-optimal, and possibly unsafe, turbine behaviour in high wind speeds.

Table 3: Calculation of Small-scale Technology Certificates for installation of the SOMA 1000 in Australia

Annual average hub-height wind speed at site (m s^{-1})	Lower range of extrapolated AEP after 3 months testing (MWh)	STCs calculated for lower estimate for 5 year deeming period	Upper range of extrapolated AEP after 20 months testing (MWh)	No. STCs calculated for upper estimate for 5 year deeming period
4	0.649	3	0.859	4
5	1.432	6	1.642	7
6	2.354	11	2.582	12
7	3.302	15	3.565	16
8	4.203	19	4.514	21
9	5.022	23	5.390	25
10	5.748	27	6.716	29
11	6.382	30	6.870	32

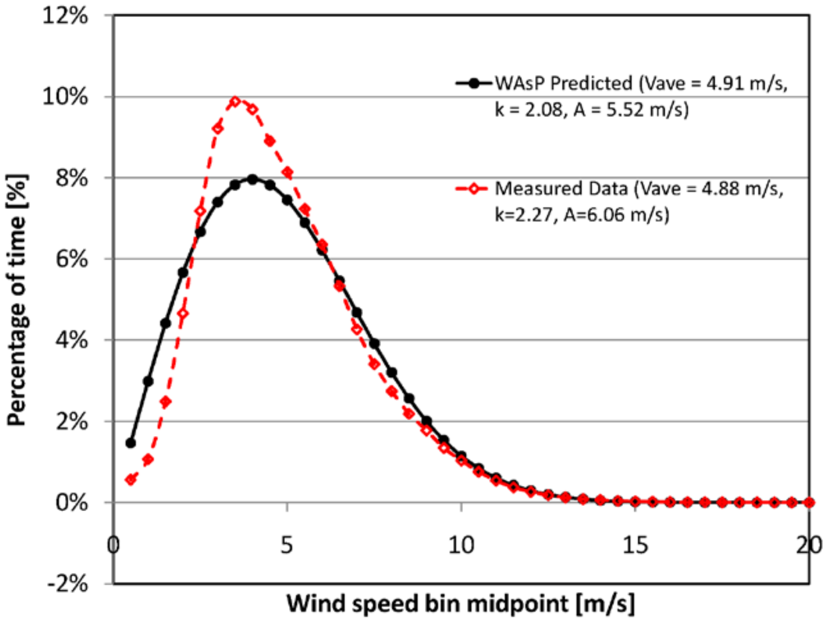

Fig. 6. Comparison of the WAsP predicted wind speed distribution to the wind speed distribution as measured over 20 months.

5. Conclusions

The characterisation of the wind resource at a SWT test site is fundamental to completing the database for power performance testing. The choice of site, however, is likely to be constrained due to non-wind resource considerations such as lease costs, tenure, accessibility and security. A wind model and spreadsheet analysis was successfully used to aid the scope and scheduling of completed power performance testing at the NSWTC test site. The wind modelling proved useful despite some discrepancies with measured data, likely due to model limitations which require further analysis. The modelling and subsequent analysis predicted Winter and early Spring to be the best time of year to test turbines, and placed a restriction on the types of turbines tested at the site. These restrictions included testing SWTs that would need to be completely furled at around 17 m s^{-1}or have a rated wind speed of approximately 12 m s^{-1}, depending on which test standard was used. However, the authors note that the choice of rated wind speed can be an arbitrary process for manufacturers [11], and the spreadsheet analysis model requires further assessment to incorporate non-ideal SWT power curves. Although a power curve can be completed in a few months, this research shows longer tests are advisable to reduce uncertainty with the power curve values at higher wind speeds, particularly in relation to furling characterisation. The known challenges of furling characterisation and reducing power curve uncertainty at higher wind speeds [12], led to the recommendation to extend testing of the SOMA 1000 at the NSWTC site to a total of 2 years, consistent with the recommended figure of between 1 and 2 years suggested by the SWCC [22]. The discrepancies observed between the measured power curve for the SOMA 1000 and the manufacturer's claims were consistent with several independent observations of SWTs (See [6, 11-13, 20, 28, 29]). However, the AEP curves generated by the measured power curve data were in high agreement with manufacturer published data for the SOMA 1000, and with the IEA recommendation, and work by Bowen [12] of using the AEP as a more objective means of comparing wind turbine performance. Although the length of the testing period becomes more important at sites with higher mean wind speeds, testing time is unlikely to have a significant influence of the AEP at 5 m s^{-1}, as used in the IEA recommended practice for consumer labelling practice [18]. This research raises the possibility, however, that the testing time has more of an influence on SWT safety in high wind speeds than performance. Further research is required in relation to SWT power curve testing and certification, and the level of testing uncertainty is considered acceptable for all parties concerned.

Acknowledgements

The authors would like to acknowledge the Australian Federal Department of Climate Change and Energy Efficiency for providing funding for the NSWTC, as well as SOMA Renewable Energy Solutions for agreeing to the SOMA 1000 being tested. In addition, various people have performed analyses that have contributed to this work: Ross Billing compiled the list of SWT characteristics; Ga Rick Lee completed some initial WAsP modelling of the NSWTC site, and; Daniel Jones of the NSWTC at Murdoch University analysed logged data from the SOMA 1000. The authors would also like to acknowledge the support of their peers in the IEC TC88 MT2 and IEA Task 27 working groups.

References

[1] Whale J, Brix B. The National Small Wind Turbine Centre: activities in standards and labelling. 57th Australian and New Zealand Solar Energy Society (ANZSES) Solar09 Conference, Townsville, Australia, 29 Sep 2 Oct 2009.

[2] Ross SJ, McHenry MP, Whale J. The impact of state feed-in tariffs and federal tradable quota support policies on grid-connected small wind turbine installed capacity in Australia. Renewable Energy 2012:DOI 10.1016/j.renene.2012.03.019.

[3] American Wind Energy Association. AWEA 2010 small wind turbine global market study, year ending 2009. 2010. Available from: http://www.awea.org/_cs_upload/learnabout/smallwind/4420_1.pdf (accessed 20 April 2012).

[4] RenewableUK. Small wind systems, UK 2011 market report. 2011 Available from: http://www.bwea.com/pdf/small/Small_Wind_Systems_Market_Report_2011.pdf (accessed 25 September 2011).

[5] American Wind Energy Association. AWEA small wind turbine global market study 2008, year ending 2007. 2008. Available from: http://www.awea.org/learnabout/smallwind/upload/2008_AWEA_Small_Wind_Turbine_Global_Market_Study.pdf (accessed 20 April 2012).

[6] Gipe P. The need for an international small wind turbine test centre. 1997 Available from: http://www.wind-works.org/articles/NeedTest.html (accessed 26 August 2011).

[7] Ruin S, Thor S-E. Summary of IEA RD&D Wind – 49th topical expert meeting on challenges of introducing reliable small wind turbines. Stockholm, Sweden: 2006. Available from: http://www.ieawind.org/task_11/topical_expert/TEM_PDF_Presentations/49_Small_Wind_Turbines.pdf (accessed 20 April 2012).

[8] Whale J. Design and construction of a simple blade pitch measurement system for small wind turbines. Renewable Energy 2009;34(2):425-429.

[9] Lange M. On the uncertainty of wind power predictions - analysis of the forecast accuracy and statistical distribution of errors. Journal of Solar Energy Engineering 2005;127(2):177-184.

[10] Gottschall J, Peinke J. How to improve the estimation of power curves for wind turbines. Environmental Research Letters 2008;3(1):015005 (7pp).

[11] Gipe P. Testing the power curves of small wind turbines. 2000 Available from: http://www.wind-works.org/articles/PowerCurves.html (accessed 28 August 2011).

[12] Bowen AJ, Zakay N, Ives RL. The field performance of a remote 10 kW wind turbine. Renewable Energy 2003;28:13-33.

[13] Li S, Wunsch DC, O'Hair E, Giesselmann MG. Comparative analysis of regression and artificial neural network models for wind turbine power curve estimation. Journal of Solar Energy Engineering 2001;123:327-332.

[14] American Wind Energy Association. Small wind turbine performance and safety standard, version 9.1. 2009. Available from: http://www.awea.org/learnabout/smallwind/upload/AWEA_Small_Turbine_Standard_Adopted_Dec09.pdf (accessed 20 April 2012).

[15] RenewableUK. British Wind Energy Association small wind turbine performance and safety standard, 29 Feb 2008. 2008. Available from: http://www.bwea.com/pdf/small/BWEA_SWT_Standard_Feb2008.pdf (accessed 29 February 2008).

[16] Whale J, Malla A. Scheduling power performance testing at the National Small Wind Turbine Centre. Solar2011, the 49th AuSES Annual Conference, Sydney, Australia, 30 November - 2 December 2011.

[17] International Organization for Standardization. Guide to the expression of uncertainty in measurement, second edition, ISBN 92-67-10188-9. Geneva, Switzerland: 2005.

[18] International Energy Agency Wind. Recommended practices for wind turbine testing and evaluation: 12. consumer label for small wind turbines (1st edition). 2011. Available from: http://www.ieawind.org/index_page_postings/Consumer_label_RP%2012%20approved.pdf (accessed 20 April 2012).

[19] Encraft. Warwick wind trials final report. 2009. Available from: http://www.warwickwindtrials.org.uk/resources/Warwick+Wind+Trials+Final+Report+.pdf (accessed 20 April 2012).

[20] Gipe P. Calculated yield of small wind turbines at Zeeland test site. 2009 Available from: http://www.wind-works.org/SmallTurbines/CalculatedYieldofSmallWindTurbinesatZeelandTestSite.html (accessed 26 August 2011).

[21] Bowen A, Huskey A, Link H, Sinclair K, Forsyth T, Jager D, van Dam J, Smith J. Small wind turbine testing results from the National Renewable Energy Laboratory. Windpower 2009, Chicago, Illinios, USA, 4-7 May 2009.

[22] Small Wind Certification Council. Frequently asked questions. 2011 Available from: http://www.smallwindcertification.org/faqs/ (accessed 26 August 2011).

[23] International Electrotechnical Committee. IEC 61400-12-1 ed1.0 Wind turbines - part 12-1: power performance of electricity producing wind turbines. 2005. Available from: http://webstore.iec.ch/webstore/webstore.nsf/Artnum_PK/35360 (accessed 20 April 2012).

[24] Mortensen NG, Heathfield DN, Myllerup L, Landberg L, Rathmann O. Getting Started with WAsP 9. Risø-I-2571(EN), Risø National Laboratory; 2007. Available from: http://www.wasp.dk/Download/General.aspx (accessed 20 April 2012).

[25] Bowen AJ, Mortensen NG. Exploring the limits of WAsP, the wind atlas analysis and application program. European Union Wind Energy Conference, Goteborg, Sweden, 20-24 May 1996.

[26] Troen I, Petersen EL. European wind atlas. Roskilde, Denmark, Risø National Laboratory, 1989.

[27] SOMA. Renewable Energy Solutions, SOMA 1000. 2009 Available from: http://www.somapower.com.au/wind_Soma1000.html (accessed 26 August 2011).

[28] Corbus D, Prascher D. Analysis and comparison of test results from the small wind research turbine test project (preprint). Golden, Colorado, USA: National Renewable Energy Laboratory; 2004.

[29] Ale JAV, Adegas FD, Simioni GC. Methodologies for power curve test of small wind turbines. Windpower, Denver, Colorado, USA, 2005.

[30] Celik AN. Energy output estimation for small-scale wind power generators using Weibull-representative wind data. Journal of Wind Engineering 2003;91:693-707.

[31] Kamp LM, Smiths REHM, Andriesse CD. Notions on learning applied to wind turbine development in the Netherlands and Denmark. Energy Policy 2004;32:1625-1637.

[32] Australian Government Clean Energy Regulator. Renewable Energy Target, What you need to know about Small-scale Technology Certificates, Commonwealth of Australia April 2012, http://ret.cleanenergyregulator.gov.au/ArticleDocuments/205/RET%20pamphlet.pdf.aspx (accessed 28 August 2012).

[33] Australian Government Clean Energy Regulator. Small Generation Unit STC Calculator version 2.10.0, https://www.rec-registry.gov.au/sguCalculatorInit.shtml (accessed 28 August 2012).