Wind Resource Assesment and Turbine Selection: Case Study for Mannar, Sri Lanka

K.M.T.Kalpage, K.R.D. Peiris, K.A.I.R.P.Perera, M.G.C.I. Siriwardana, N.W.A. Lidula
Department of Electrical Engineering
University of Moratuwa, Moratuwa, Sri Lanka.

M.T.A.P. Wickramarathna
Ceylon Electricity Board, Sri Lanka.

***Abstract*—In deploying a large scale wind power plant, there are several aspects that have to be assessed. Among them the initial site screening for wind power plants, wind data assessment and proper selection of wind turbines are vital for the success of the project. This paper presents a step by step analysis in selecting a wind turbine, as a case study for Sri Lanka, where it has a substantial amount of wind energy that can be harnessed for power generation. Mannar area is identified as the candidate site with the high wind potential it exhibits throughout the year. After a detailed analysis of the wind resource in Mannar area, Gamesa-114 2 MW wind turbine is selected as the most suitable wind turbine for this particular area of Sri Lanka.**

Keywords*— *Wind data assessment, wind power, wind turbine selection

I. Introduction

The increase in fuel prices, population growth and industrialization have triggered various problems worldwide including the energy crisis. The unmitigated consequences of the carbon dependent economy, governed by an intensive use of fossil fuels have contributed to alter the energy policies around the world. Energy consultants have started brainstorming and scouting for safer cleaner and quality energy sources, pertaining to the constraints imposed by the sustainable energy policies. These new energy policies have become the key driving factor for the renewable energy expansion in the recent past. In this context, renewable energy sources like solar and wind are gaining much attention mainly due to their lower environmental impact.

The government of Sri Lanka has also started complying with these novel energy policies and it has been decided that the energy contribution from Non-conventional renewable energy (NCRE) plants will be maintained above 20% from 2020 onwards [1]. In comparison with large conventional power plants, the total contribution from the NCRE sector to the national grid in Sri Lanka still remains small but continues to increase and in 2014 the energy share of NCRE was 9.8% [1]. Among all the renewable energy sources, use of wind energy for power generation has gained high interest in Sri Lanka. It is estimated that there is approximately 5000 km^2 of windy areas with good to excellent wind resource potential in Sri Lanka [2].

Initial site screening for wind power plants, wind resource assessment and proper selection of wind turbine types are vital for the success of any wind project. The governing factor for the selection of a wind plant site is the wind resource itself. So in the site screening process the initial screening and assessments of the wind resource and the land suitability is discussed. Apart from that, transportation and transmission access aspects must also be evaluated. The wind turbine selection process is carried out matching the wind turbine parameters with the site conditions such as, air density, wind speed (frequency of each measured wind speed) and wind direction.

II. Wind Resource in Sri Lanka and Site Selection

Six percent of the total land area of Sri Lanka (65,610 km^2) is identified as windy lands. By using a conservative assumption of 5 MW per km^2, it can be evaluated that Sri Lanka has the capability to support more than 20,000 MW of potential installed capacity [2]. The first commercial wind power plant was established in 2010 and the total capacity of wind power plants by the end of 2014 was 124 MW [1]. Three main regions, namely North-Western coastal region from Kalpitiya Peninsula north to the Mannar islands, central highlands and Southeast coast from Hambanthota to Buthawa, can be identified as having good to excellent wind resource in Sri Lanka. In this paper, Mannar, region is selected as the candidate site as it inherits a good wind potential throughout the year. Fig. 1 depicts the wind regime of Mannar region over Ambewela and Hambanthota areas, for most of the time in the given year [3].

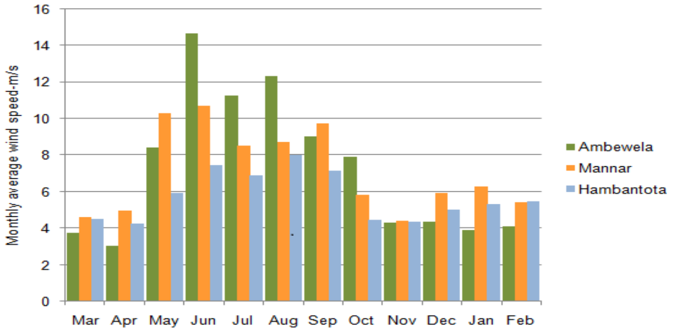

Fig. 1. Monthly average wind speeds in Ambewela, Mannar and Hambanthota.

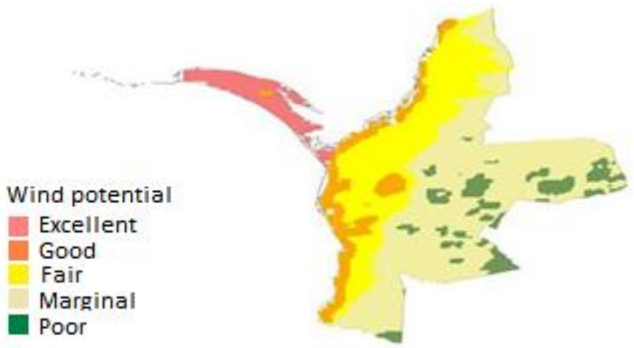

Fig. 2. Spatial distribution of Mannar region [5]

A good wind energy resource will only be beneficial if energy generated by the project can be effectively delivered to the organization purchasing the energy. Hence, aspects of transportation and transmission access should also be considered. Mannar area is proven to have an upper hand over the other candidate sites with respect to proximity of transmission lines, terrain, aviation and telecom conflicts etc. [4]. Considering the completed as well as ongoing road development projects in Northwestern coast of Sri Lanka, Mannar region has grown well ahead in accessibility as well.

Furthermore, Mannar area has been already selected as a candidate site for a 375 MW wind farm project. In the long term generation expansion plan (2015-2034) it is clearly stated that the first 100 MW semi dispatchable wind farm will be developed by 2018 in Mannar and the remaining 275 MW will be developed in two phases. Thus, it is of paramount importance that a proper site screening and turbine selection to be conducted for this area [1].

Mannar district covers 2000 km^2 of the Sri Lankan land area and the population is approximated to be 100,000 in 2012. The annual rainfall is less than 1000 mm/year and nearly 65% of the land area is covered by forest. Main economic activities of the population include agriculture, fishery and livestock farming [3]. Fig. 2 depicts the wind distribution in Mannar, which shows a fair to excellent wind spatial distribution for most parts within the region.

III. WIND DATA ASSESSMENT

A. *Wind data measuring*

Mannar district has three wind data measuring stations located in Silawathura, Nantnathan and in Nadukuda. Table I gives the measured years of wind data and the available durations for each of this measuring stations.

TABLE I. WIND DATA MEASURING STATIONS IN MANNAR [2]

	Location	District	Wind Data (Years)	Availability (months)
1	Silawatura	Mannar	2011, 2012	16
2	Natnathan	Mannar	2011, 2012	19
3	Nadukuda	Mannar	2011	8

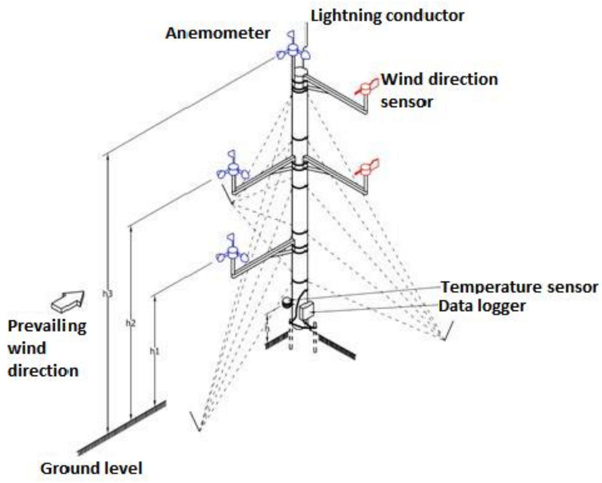

Fig. 3. A wind mast

For this study wind data measurements of Nadukuda area obtained through Sri Lanka Sustainable Energy Authority (SLSEA) was used. These data had been collected using three wind masts located in the Nadukuda area. A schematic of a wind mast is shown in Fig. 3 and it can be described as a free standing measurement tower or a removed mast, which carries measuring instruments such as thermometers, wind direction measurers like wind vanes and wind velocity measurers like anemometers [6].

Average speed (m/s), Direction (deg) and temperature (^{0}C) were the main data measures which were obtained at heights of 10 m, 25 m, 40 m, and 50 m above ground. These measurements had been recorded in a sample time of 10 minutes for duration of 9 months (2011/06/01– 2012/02/29).

The wind data was analyzed using the "Windographer" software tool, which is well renowned for its capability for analyzing wind resource data. It can import raw data files quickly, display the data in sophisticated interactive graphics, provide powerful quality control capabilities and perform comprehensive statistical analyses, and create high-quality output [7].

After analyzing the imported raw data, Windographer first delivers a summary of wind speed and power, environmental conditions and wind shear coefficients. For an example, after analyzing the given data at a height of 50 m, the mean speed and power density were given as 10.4 ms^{-1} and 270 Wm^{-2} respectively. The value 270 Wm^{-2} implies a wind power class of 2, which is an indication of the mean wind energy content of the wind resource. Pertaining to a wind power class of 2, the mean wind energy content can be stated as marginal. Under environmental condition, the mean temperature was estimated to be 27.6 ^{0}C whereas the mean pressure and mean air density were estimated to be 101.3 kPa and 1.173 kgm^{-3} respectively. Wind shear coefficients were also evaluated and the power law exponent (a number that characterizes the rate at which wind speed changes with height above ground) was 0.214, while the surface roughness (a measure of the rate at which the wind speed changes with height above ground) had a value of 0.0381.

Furthermore, this software package was used to obtain the vertical wind shear profile, wind frequency rose, diurnal wind speed profiles, and frequency histograms for the imported data.

B. *Vertical wind shear profile*

Vertical wind shear profile depicts the increase of wind speed with height above ground. Fig. 4 shows the vertical wind shear profile for the wind speeds obtained through all three masts, along with the logarithmic law and power law profiles that best fit those mean wind speeds. In here a roughness class (a dimension based on surface roughness) of 1.2 was taken.

C. *Mean diuranal wind speed profile*

Mean diurnal wind speed profile is used to display the average daily wind profile for the wind speeds measured using Mast1 (M1), Mast2 (M2) and Mast3 (M3) at the available heights.

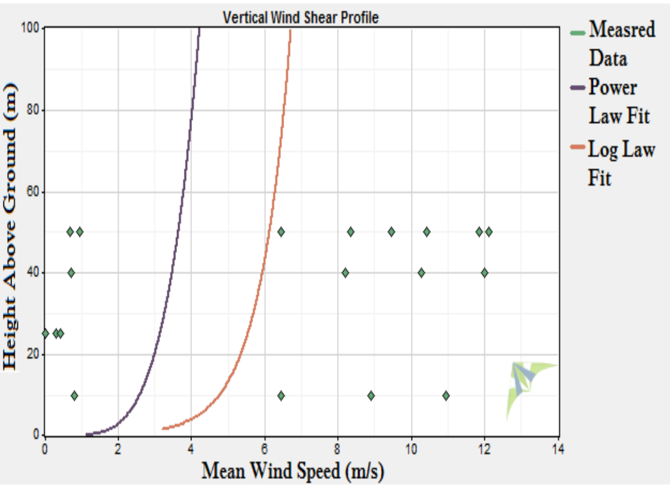

Fig. 4. Vertical wind shear profile

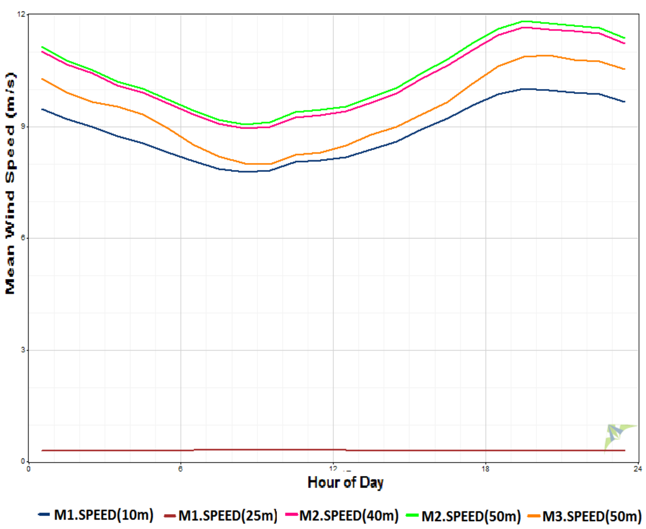

Fig. 5. Mean diurnal profile

According to mean diurnal wind profiles of all nine months, M2 at 40 m (M2_40) and 50 m (M2_50) heights, and M3 at 50 m (M3_50) height showed higher diurnal wind speed profiles with respect to other measurements. Fig. 5 shows a single profile averaging all the diurnal wind data profiles for all nine months into one. Wind speed profile of M2_50 is greater than the ones obtained for the M2_40 and M3_50. Comparing M2_40 and M2_50 it can be stated that the wind speed increases with height. But, considering the fact that the mean diurnal profile of M3_50 is lower than both M2_40 and M2_50, it can be identified that the wind speed has a clear variation between the two measuring points considered. With these results Mast2 can be identified as a good measuring point with higher wind potential.

D. *Wind frequency rose*

A wind rose is a graphical tool used by meteorologists to give a clear view of how wind speeds are typically distributed at a particular location.

In Nadukuda the wind direction data was obtained using the direction sensors (wind vanes) installed in M1_10, M2_25, M3_50. Radius gives an indication of frequency in a wind rose. Fig.6 implies that the wind direction distribution shows a Southwesterly wind about 45% - 50% of the time.Fig.7 depicts the monthly direction variation for M3_50, which further indicate a southerly wind pattern.

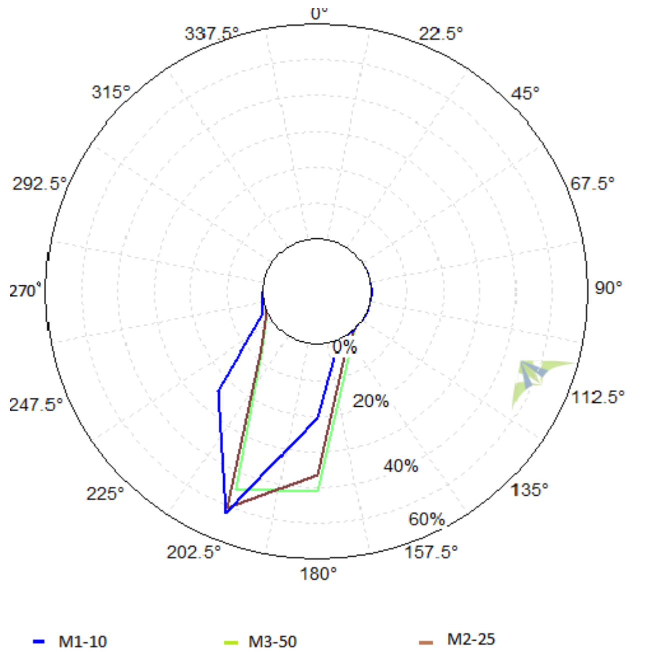

Fig. 6. Wind frequency rose versus the direction sensors at the available heights

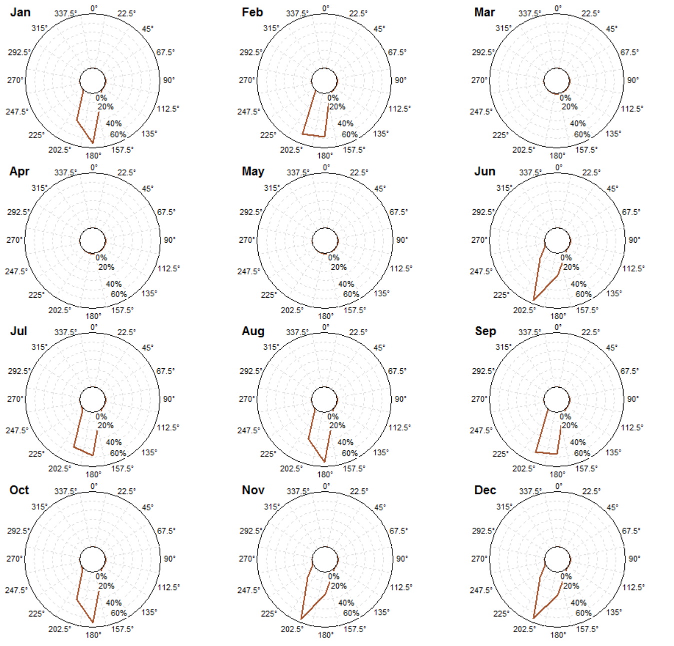

Fig. 7. Wind frequency rose of M3_50 wind direction sensor for all nine months

E. *Probability distribution function(PDF)*

Probability distribution function can be used to get the frequencies of a set of speed ranges. In Windographer a speed range of 0 to 1 ms^{-1} is used by default. Windographer also plot the best-fit Weibull distribution (calculated using the maximum likelihood algorithm) giving a clear indication of how well it fits the actual distribution of wind speeds.

The Weibull distribution which is often a good approximation for the wind speed distribution is given by;

$$f(u)=\frac{k}{c}\left(\frac{u}{c}\right)^{k-1}\exp\left[-\left(\frac{u}{c}\right)^{k}\right] \qquad (1)$$

Where;
u: wind speed (ms^{-1})

c: Weibull scale factor (ms^{-1}) (a measure for the characteristic wind speed of the distribution and is proportional to the mean wind speed)

k: Weibull form factor (It specifies the shape of a Weibull distribution. A small value for k (usually in between 1 to 3) signifies broader distributions corresponding to variable wind speeds, whereas higher *k* values (above 3) signify tighter distributions corresponding to constant wind speeds [8].

PDF obtained for M2_40, M2_50, M3_50 are shown in Figs. 8, 9 and 10 respectively, along with their Weibull distribution. According to Fig. 8 and Fig. 9, M2_40 and M2_50 have *k* values greater than 4, which indicate constant wind speeds in the measuring point. The mean wind speed can be approximated to 11 ms^{-1} at that measuring point.

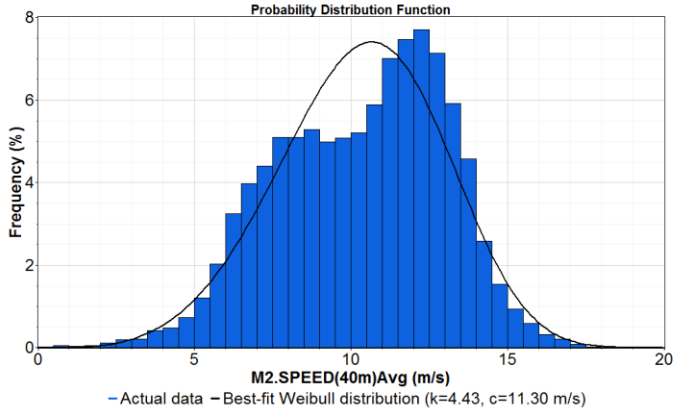

Fig. 8. PDF of M2_40

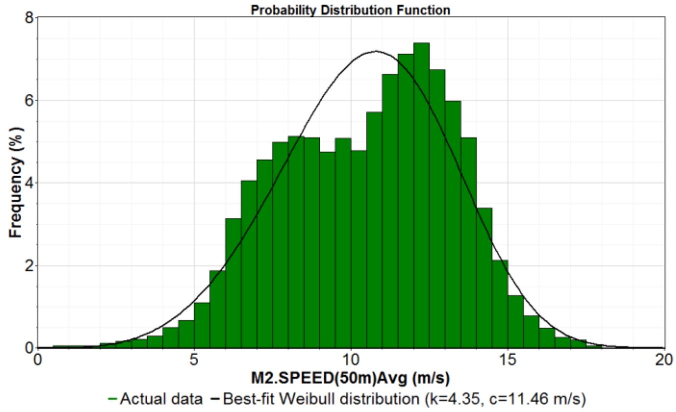

Fig. 9. PDF of M2_50

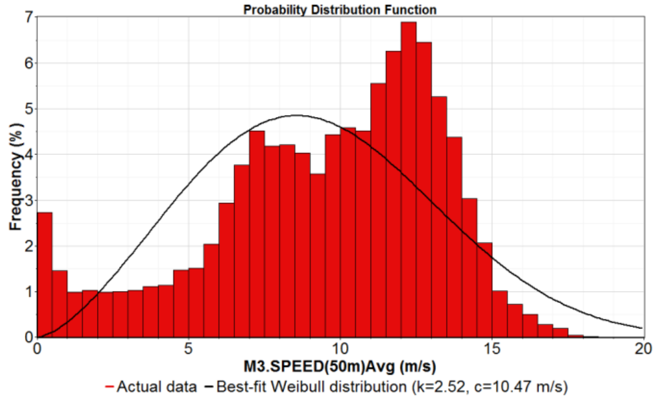

Fig. 10. PDF of M3_50

According to Fig.10, M3_50 has a *k* value of 2.52, which indicates variable wind patterns. The mean wind speed obtained was 10.47 ms^{-1}.

IV. WIND TURBINE SELECTION

A wind turbine must be placed high enough to catch strong winds, and above turbulent air, due to the fact that the wind speed increases with height and at the same time wind turbine cannot extract energy from turbulent wind [9].

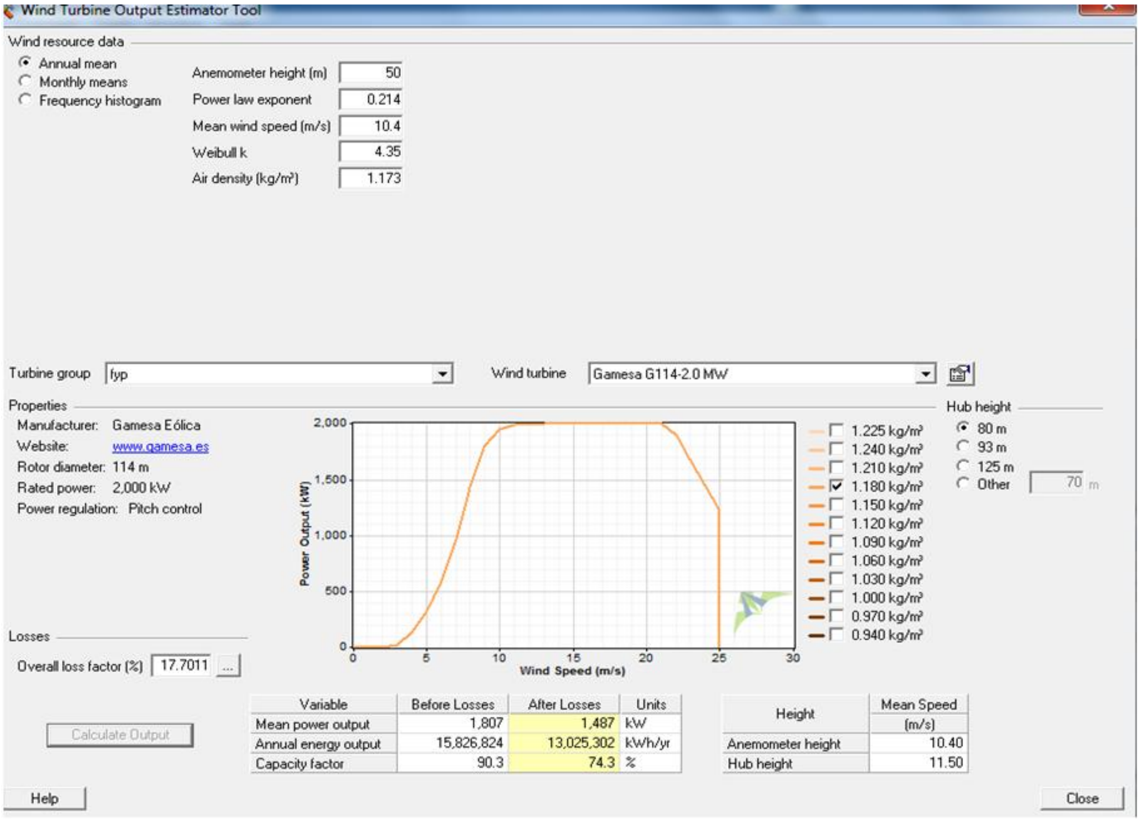

Fig. 11. Wind turbine output estimator tool

Therefore, for the turbine selection process, the data obtained from M2 (50m) was considered being the best wind data measuring point with maximum height, during the wind data assessment process. On a more special note for the turbine selection process, wind data obtained through M2_50 was considered common for all locations in Mannar area.

It is necessary to know exactly how often wind blows how strongly in order to be able to predict a wind turbine's power production for the turbine selection process. The Weibull distribution is often a good approximation to determine the wind speed distribution [9]. Through Windographer software the Weibull parameters have been obtained in the wind data assessment section. These values can then be used in the wind turbine output estimator tool in Windographer to obtain the mean power output, annual energy output and capacity factor for the selected type of wind turbines. Further, it provides the power production distribution curve of each wind turbine when it is subjected to the site parameters. An overall loss factor of 17.7011 was considered in the analysis. The wind turbine output estimator tool window along with the obtained results for the Gamesa G114-2 MW turbine is given in Fig. 11.

Using this tool the turbine output was estimated for 45 different wind turbines and the best three wind turbine types were selected out of three different categories (0-1 MW, 1-2 MW, 2-3 MW). This was done first sorting the obtained annual energy output to the mean power output ratio in descending order and then again applying the descending sorting process for the capacity factor.

The obtained results are given in Table II, and it shows that the net capacity factor is above 60% in almost all of the cases. But usually the net capacity factor of existing wind plants in Sri Lanka lies within the range of 30% to 50%. The cause of this significant deviation could happen due to the fact that the wind speed distribution of the obtained data shows a more constant wind pattern along with a higher mean wind speed of 10.4 ms^{-1} at 50m height.

Leitwind LTW77-1 MW topped the 0-1 MW category, whereas Gamesa G114-2 MW and Gamesa G114-2.5 MW topped the 1-2 MW and 2-3 MW categories respectively. Leitwind LTW77-1 MW was rejected as it would need comparatively higher number of turbines to get the required power output and the Gamesa G114-2.5 MW was rejected as it would cause difficulties when transporting turbines to the site due to their size. So finally Gamesa G114-2.0 MW turbine was selected for this particular site.

At present there are mainly four types of wind turbine technologies used worldwide namely; fixed speed wind turbine generator, dynamic rotor resistance control wind turbine generator, doubly fed induction generator and the full converter based wind turbine generator [10]. Among these wind turbine technologies Gamesa G114–2MW falls under the doubly fed induction generator type. It gives a mean power output of 1487 MW, an annual energy output of 13,025,302 kWh with a capacity factor of 70.2. Some other specifications of the selected wind turbine type, Gamesa G114 is given in Table III.

TABLE II. SELECTED BEST TURBINES OUT OF EACH CATEGORY

Category	Name	Mean power output (kW)	Annual Energy output (kWh/yr)	Capacity factor (%)	kWh/MW
0-1 MW	Leitwind LTW77-100 1 MW	702	6,150,875	70.2	6,150,875
	Unison U57 0.75 MW	520	4,554,525	69.3	6,072,700
	Unison U54 0.75 MW	493	4,320,043	65.8	5,760,057
1-2MW	Gamesa G114-2.0 MW	1487	13,025,302	74.3	6,512,651
	Vestas V110-2.0 MW	1470	12,881,258	73.5	6,440,629
	Vestas V100-1.8 MW	1301	11,396,078	72.3	6,331,154
2-3MW	Gamesa G114-2.5 MW	1781	15,604,306	71.3	6,241,722
	Vestas V112-3.0 MW Offshore	2113	18,510,580	70.4	6,190,193
	Suzlon S97-2.1 MW	1448	12,685,293	69.0	6,040,616

TABLE III. SPECIFICATIONS OF GAMESA G114 2 MW TURBINE

Specification	
General Details	***Blades***
Rated power : 2 MW	Length: 55.5 m
Wind class: IIIA	Airfoil: Gamesa
Rotor diameter : 114 m	***Tower***
Swept area: 1027 m2	Height: 93m or site specific
Power density: 195.94 W/m2	
Control : independent pitch and variable speed	
Gearbox: 3 stages	
Frequency: 50Hz/ 60Hz	

V. UNCERTANITY

A. *Duration*

For a proper wind data assessment data samples must have to be collected at least for more than two years. But for this research we have obtained data complying with a period of nine months. So this duration factor could cause some uncertainty in the results obtained.

B. *Southwest and Northeast monsoons*

The Sri Lankan wind regime is governed by the Southwest and Northeast monsoons. Southwest monsoon prevails from June to October whereas Northeast monsoon prevails from December to March. In this data sample, records have not been collected in March, April and May. This implies that measurements have been mostly collected in the two monsoon seasons. Thus, the frequency of the recorded lower wind speeds have become quite low leading to a higher mean wind speed of 10.4 ms^{-1} at 50m height above ground and a Weibull k value above 4, which eventually contributes to a higher mean power output and a capacity factor.

C. *Wind speed distribution in Sri Lanka*

The actual annual frequency distribution of Mannar consists of two peaks (bimodal distribution) corresponding to the Southwest and Northeast monsoons. Since Weibull analysis is developed to describe European wind regimes, which are simple in nature as compared to Mannar wind regime, the Weibull distribution might not be exactly following the actual wind speed distribution of Mannar, causing uncertainty in the results obtained.

VI. CONCLUSION

Mannar district can be considered as a good region for the development of large wind power projects. The detailed wind data assessment shows that Mannar area has often been subjected to constant wind speeds. The mean energy content in the wind pertains to a wind power class of 2, which is considered to be marginal. Furthermore, Mannar has a Southerly wind pattern throughout the year. Gamesa G114, 2 MW will be the most suitable wind turbine type for this region.

REFERENCES

[1] Ceylon Electricity Board, “Long term generation expansion plan 2015-2034 “, 2015.

[2] Energy.gov.lk, ' Sri Lanka Sustainable Energy Authority', 2015. [Online]. Available: http://www.energy.gov.lk/sub_pgs/energy_renewable_solar_potential.html.

[3] Sunith Fernando, “Resource assessment and wind power development for Mannar”, Capacity building for clean power development, Preparation of renewable energy development and wind park master plans and business model for wind park (part b), (presentation)

[4] M. Young , R. Vilhauer, “Sri Lanka wind farm analysis and site selection assistance”, Global energy concepts, LLC Kirkland, Washington, August 2003.

[5] National Renewable Energy Laboratory (NREL), “National wind atlas of Sri Lanka”.

[6] Thomas Neumann, Klaus Nolopp, “Three years operation of far offshore measurements at FINO1”, DEWI GmbH - Deutsches Windenergie – Institute.

[7] Windographer.com, 'Windographer | Wind Resource Assessment Software', 2015. [Online]. Available: https://www.windographer.com/.

[8] Wind-data.ch, 'Windenergie-Daten der Schweiz', 2015. [Online]. Available: http://wind-data.ch/?lng=en.

[9] Skylandsrenewableenergy.com, 'Skylands Renewable Energy | Services', 2015. [Online]. Available: http://www.skylandsrenewableenergy.com/siteselection.html.

[10] Energypedia.info, 'Wind Turbine Technology - energypedia.info', 2015. [Online]. Available: https://energypedia.info/wiki/Wind_Turbine_Technology.