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Quantitative Assessment Of Power Law Exponent And Meteorological Wind Power Potential For Eight Southern African Sites

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***Abstract*— In this paper the wind power law along with Justus's form is used to assess the wind energy potential of r eight pre-defined Southern African sites. The exponents of the power law are calculated based on hourly wind measurements at reference heights via a simple Excel spreadsheet model. The hourly average of the meteorological wind power potential of each site is determined quantitatively and the results support the deployment of wind plants across the country. Determining the exponents of these eight sites distributed over South Africa will enable further wind resources assessment studies and the building of large power plants can be accomplished based on power law with estimated exponents based on field measurements rather than assumed values**.

Index terms - wind energy, resources assessment, power law exponent. .

I. Introduction

Wind energy is one of the most promising renewable energy sources, therefore huge new constructions are being developed all over the world. According to the American Wind Energy Association, the USA installed wind power plants with a capacity of 1,084 MW during 2013 [1]. This is attributed to the continuous reduction of wind power cost whereby the cost of power from wind has been reduced by 43% over the last four years. This is a low price compared to the cost of power from other renewable energy sources; furthermore the cost is comparable with that from other conventional energy sources whereby the levelized cost of electricity (LCOE) is calculated to be approximately \$0.068/kWh for wind, \$0.067/kWh for coal, \$0.056/kWh for gas-fired generation plants In 2010 about 2.5% of the world's electricity (197 GW) was obtained from wind energy [2]. . Before putting up a wind power plant, you need local wind data. Wind data is needed to design wind turbines so that they will perform well where they are located. A techno-economic performance assessment should be done to ensure productivity [3]. Moreover, the siting of the new wind power plants primarily relies on wind resource characteristics. Therefore local assessment of wind energy resources becomes vital in order to build successful wind power.

The assessment of local wind energy resources can be done by means of field measurements, which may be problematic under certain circumstances considering the cost and technical difficulty. In other situations measurements may be available for a particular height. Due to air shear wind speeds increase at higher elevations [4], thus recent wind turbines include tall towers to extract more power from wind at higher elevations. For instance a 225 kW wind turbine is installed in a 27 m tower while a 1,500 kW wind turbine requires a 60 m tower [5]. So, theoretical methods appear as a likely methodology to evaluate wind speed at altitudes where measurements are unavailable [6] [7] [8] [9].
Assessment of wind speed theoretically via different methods has been approved worldwide. Examples are the well-known linear Jackson-Hunt model (JH), the Mesoscale numerical models (MNM), and computational fluid dynamics (CFD) [10]. Hence, wind speeds at elevations other than the elevations of the measurements are investigated by means of adopting a simple model composed of wind power law along with Justus's form. Wind speeds at eight Southern African sites have been calculated, which requires first the calculation of the exponent of the power law for each site. Finally the potential of these sites to host wind power plants was assessed. The objective was to enable the use of the power law for the prediction of wind speed using estimated exponent values rather than assumed values. This can support wind power projects.

II. MODEL

The target here is to attain a model that can be used first to calculate the wind speed at specific altitudes in certain sites, and then to evaluate the wind power potential at these sites. It is desirable to have a simple model with regard to implementation and solution. Thus, the model used here is adopted from [3], and it is composed of power law integrated with Justus's form [11]. The assessment of the level of potential of each site as a wind power plant is determined. The sites are identified as poor sites, good sites, or excellent sites as follows:

$$P'' < 100\ W/m^2$$

$$P'' \cong 400\, W/m^2$$

$$P'' > 700\, W/m^2$$

P'' stands for hourly average wind power. This is calculated by considering the meteorological wind potential which is equivalent to the available wind resources according to the World Energy council [12]. This is the maximum potential for any site that can be achieved if there are no limitations of the land available to build the plant in the considered site. Meteorological wind power potential is given by:

$$P'' = \frac{\rho_a}{2N} \sum_{i=1}^{N} U_i^3$$

ρ_a is the density of the air (Kg/m^3), N is the number of measurements, and U_i is the hourly average wind speed (m/s). The time series of U_i at a certain height above the ground (Z) is calculated from the wind speed velocity record U_{io} measured at a reference height, lower height (Z_o), via the wind power law given by:

$$U_i = U_{io}[Z/Z_o]^{\alpha}$$

The exponent (α) of the power law for each site (i) is calculated individually from Justus's form:

$$\alpha_i = \frac{0.37 - 0.088\,Ln(U_{io})}{1 - 0.088\,Ln\,(Z_o/10)}$$

III. WIND DATA PROCUREMENT AND PROCEEDING

A record of the average value of hourly wind speed data over the time interval 01/01/2010 – 31/ 12/2010 measured at 10 m height are attained for eight Southern African wind farms (cookhouse, Dorper, hopefieldd, Jeffrey, Metro, Nobel and Red Cap) [13] data are used to find the best fit of the power law exponent (α) for each site separately. Figure 1 shows these data for two locations which are Red Cap and Cookhouse. Wind velocity changes significantly and continuously. Since listing 8760*8 values herein appear inapplicable, we resort to giving statistical values representing these wind speeds for the different eight farms [14]. This sentence does not make sense. The maximum, minimum, and average values are presented in Fig. 2. This also shows the gap between the maximum and minimum values of wind speed over the year.

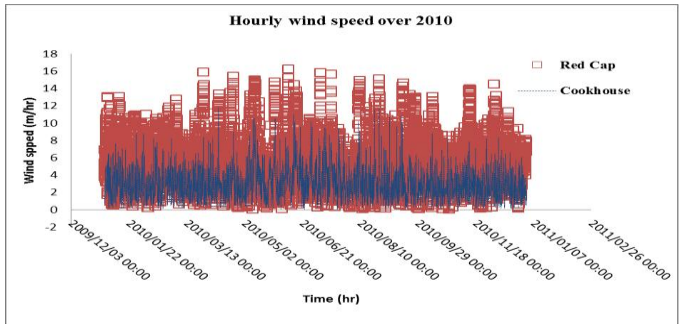

Figure 1. Hourly record of wind speed at 10 m above ground

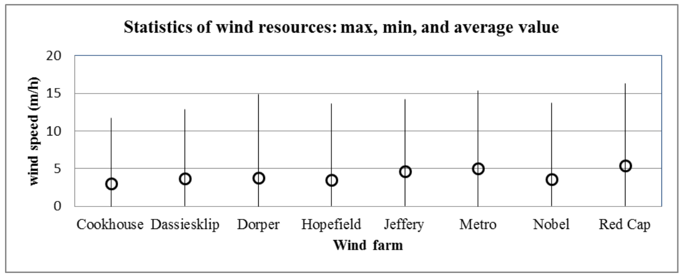

Figure 2. Wind resources characteristics at 10 m height in 8 wind farms

These data records have been used to solve the model given in Section 2; firstly the values of the exponent of the power law for each site were found. Then the calculated coefficients were used to estimate the wind speed at the height of 100 m. Finally the wind meteorological potential was calculated as a means to evaluate the suitability of each site for the building of wind power plants.

IV. RESULTS AND DISCUSSION

A. *Power law coefficients*

Classical regression was performed using the data given in Sec. 3 to find the optimum fit of the exponent value of the power law; this is done for each site individually. The attained α values are listed in Table 1. The importance of this step is that it makes it possible to give estimated α values to be used herein and in further studies to be conducted rather than employing assumed ones. This is anticipated to enhance the technical feasibility studies directed to extending the construction of wind power plants so that they can contribute more to the national energy portfolio.

Table 1. Estimated values of the exponent of the wind power law

Wind farm	Power law coefficient (α)
Cookhouse	0.317
Dassiesklip	0.294
Dorper	0.293

Hopefield	0.292
Jeffery	0.302
Metro	0.272
Nobel	0.270
Red Cap	0.301

These high α values indicate that a significant increase in wind speed is achieved at higher elevations. According to [4] wind speed is highly sensitive to the height of the tower of the wind turbine.

B. Predicting wind speed at the height of 100 m.

After estimating the exponent of the power law for each site, the power law along with these estimated values is employed to estimate the wind speed at a height of 100 m. This altitude was selected since wind turbines especially when used in huge wind farms generally have tall towers tin order to gain benefits from the increased wind speeds [Patel, 2006]. Moreover, a growing trend is to build larger wind power plants. [5]. A tower of 100 m is suitable for large wind farms, megawatts wind farms, for example a 5000 kW wind turbines demand a tower of 100-110 in height [3]. Thus a height of 100 m is selected for this study to indicate the positive effect of large heights on the performance of wind power plants, and to emphasize the objective of the study which is the evaluation of wind speeds at heights where there is a lack of field measurements appropriate for large wind turbines. Figures 3 to 9 represent the estimated wind speed at 100 m and compare them with the corresponding values at 10 m. In general a significant increase in wind speed is achieved, which points to the importance of constructing wind turbines at the right height above the ground to maximize the power productivity.

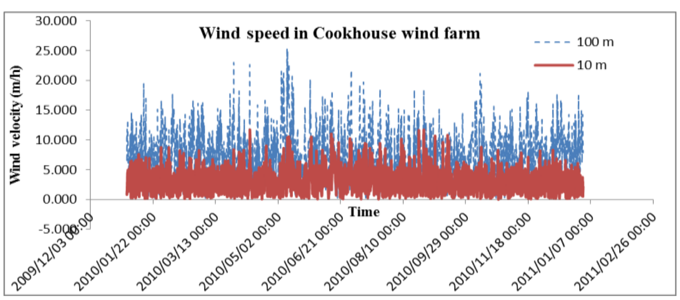

Figure 3. Comparison between wind speed at heights of 1 m and 100 m at Cookhouse farm.

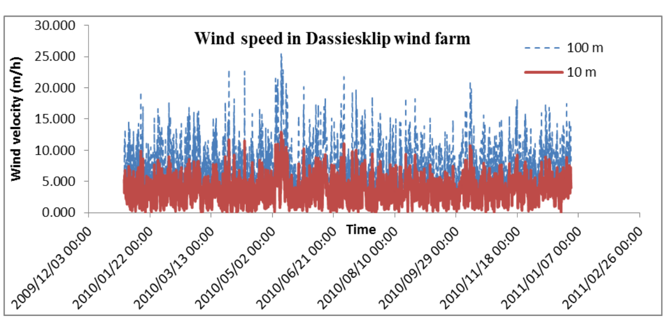

Figure 4. Comparison between wind velocity at heights of 1 m and 100 m at Cookhouse farm.

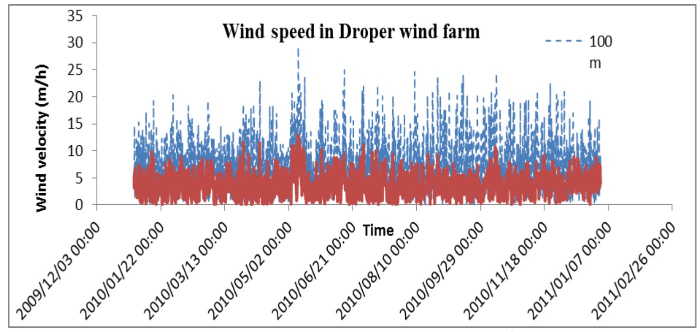

Figure 5. Comparison between wind velocity at heights of 1 m and 100 m at Cookhouse farm.

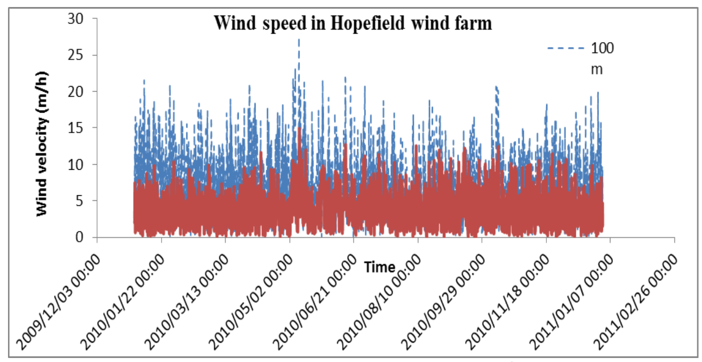

Figure 6. Comparison between wind velocity at heights of 1 m and 100 m at Hopefield farm.

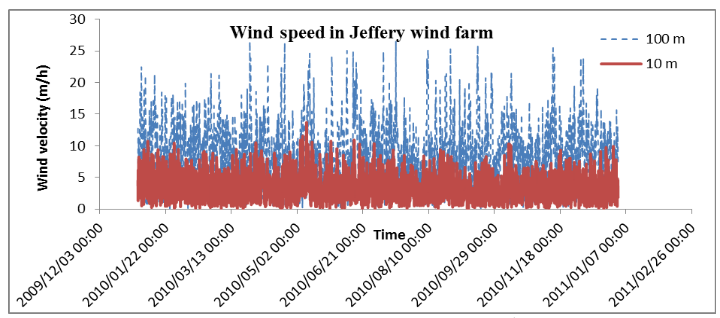

Figure 7. Comparison between wind velocity at heights of 1 m and 100 m at Jeffery farm.

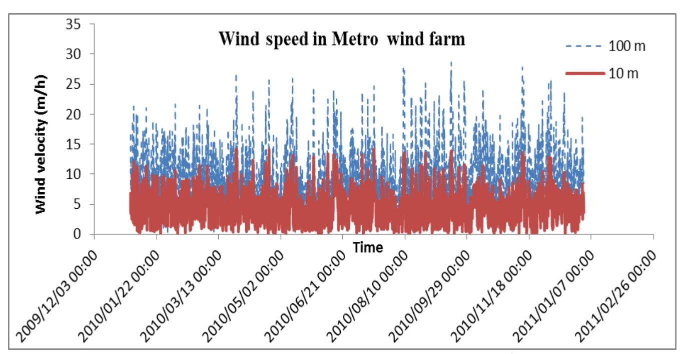

Figure 8. Comparison between wind velocity at heights of 1 m and 100 m at Nobel farm.

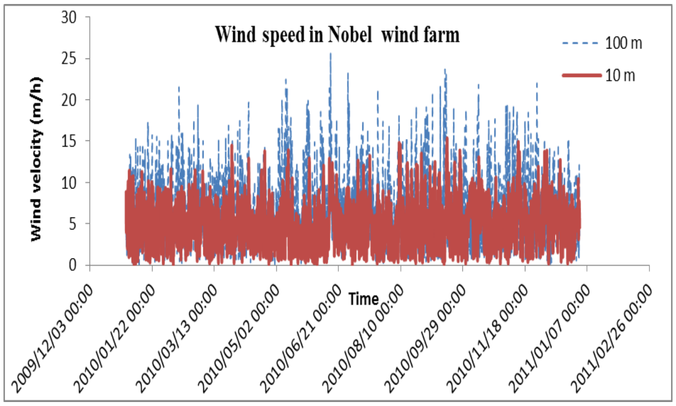

Figure 9. Comparison between wind velocity at heights of 1 m and 100 m in Nobel farm.

Fig. 10 Comparison between wind velocity at heights of 1 m and 100 m at Red Cap farm Statistics have been drawn up with regard to the wind speeds at the two heights. So, the maximum, minimum, and average wind speeds have been calculated for each site and at each height. These values have been plotted in one diagram, Fig. 10, to show the differences and to make it possible to reflect how much change can take place by changing the height at which wind turbines are installed.

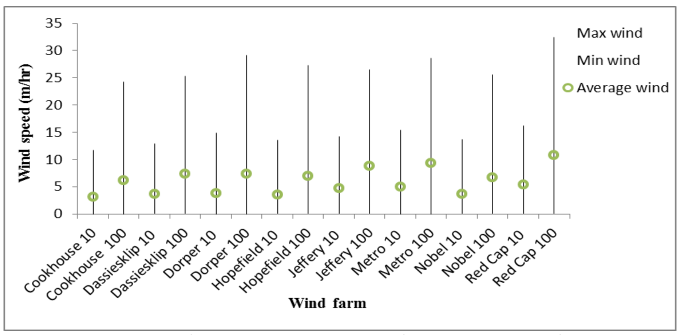

Figure 10. Statistics of wind speed at heights of 10 m and 100 m for the eight sites.

C. Evaluation of the meteorological wind power

In this section the positive impact of extracting wind by turbines at 100 height, rather than 10 m is discussed and the meteorological wind power potential for the eight sites is estimated in order to assess the feasibility of building power plants there. Whether the site is poor, good, or excellent for the building of a wind plant is evaluated in terms of hourly average power value (meteorological value), calculated at 10 m once and at 100 m another time. Figure 11 represents the hourly average power potential at 10 m and at 100 m for each plant. Meanwhile there are 3 horizontal lines at power values of 100, 400, and 700 W/m$^{2.}$ These are in red, green, and blue respectively from the bottom up. According to [3] if the power potential value of a plant falls below the red line, the site represented by that curve is a poor site (if the turbines are built at the given height) and building of a power plant is not recommended there. . Sites shown around the green line have power values close to 400 W/m^2 and are good sites; however sites located above the blue line are the excellent sites for the building of wind power plants.

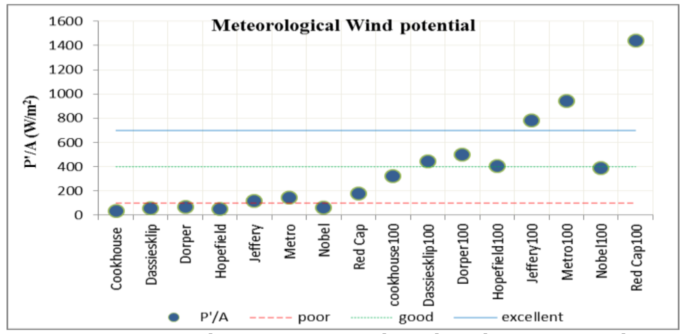

Figure 11. Estimated average m meteorological wind power potential

According the results, Red Cap is the best choice of site to build a wind power plant, then Metro, and then Jeffry. The meteorological wind power potential at Red Cap is above 700 W/m2. Then the other five sites are good since they fall around the green line in Fig. 11 which means the hourly average power potential is about 400 W/m2. These five sites may be sorted in descending order: Droper, Dassieklip, Hopefield, Nobel, and Cookhouse.

V. CONCLUSIONS

The prediction of wind speed at heights such as 100 m can be done using wind power law, but the exponents of this law need to be calculated rather than assuming their value in order to successfully predit the wind speed at particular heights. Measurements of wind speed at 10 m above the ground in eight sites were exploited to estimate the exponent of the power law for each site. Then the law was solved at the study considered height (100 m) to obtain the corresponding wind values. Based on these obtained wind values, the hourly average wind power meteorological potential was estimated for each site. From the obtained results, it can be seen that:

- The exponent of the wind power law has been calculated from hourly measurements of a year for each site
- The estimated exponent values need to be estimated for each particular site individually rather than assumed since the results show each site has its own value
- Wind power potential varies significantly with the height of the turbines
- The studied Southern African sites have potential for the building successful wind power plants, the potential ranges from good to excellent.

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