DETERMINATION OF THE POWER LAW EXPONENT FOR SOUTHERN HIGHLANDS OF TANZANIA

HH Mwanyika and RM Kainkwa
Department of Physics, University of Dar es Salaam, P.O Box 35063,
Dar es Salaam, Tanzania.

ABSTRACT

The 1/7th power law is among the methods that have been used to extrapolate wind speed to the hub heights of wind turbines from the measuring levels. However, it tends to underestimate the actual long-term average wind speeds. In this paper, the power law exponent for Makambako, a site located in the southern highland zone of Tanzania, was established using wind speeds measured at heights Z_1=2 m and Z_2=7 m. The average power law exponent obtained at the test site was 0.47, a value that is substantially higher than the 1/7th power law exponent. It is low during the dry season and high during the rainy season. Values of the exponent higher than the overall mean were observed during the night while lower values were detected during the daytime. The overall mean value of the exponent determined from this trial site can be used to project wind speed to desired heights in areas with similar topographical features especially those in the southern highlands of Tanzania, in which the experimental site is situated.

INTRODUCTION

Wind energy harnessing requires knowledge on wind speed, wind direction, wind speed distribution, turbulence and wind gusts at the prospective site before the installation of electric wind energy conversion systems (WMO, 1981; AWEA, 2001). The wind speed which is one of the prime characteristics of wind varies in both space and time. It varies largely with height above the ground. Wind speed increases rapidly with height in mountainous and complex surfaces compared to smooth surfaces. At low wind speeds the change in speed with height is less pronounced and more erratic (Dobeschs and Kury 2001, Farrugia 2002).

Though the standard height for measuring wind speed for wind resource assessment is 10 m above the effective ground level, but it can be necessary to determine the wind speed at higher levels such as those of towers of typical wind turbines which are much taller than 10 m height (WMO 1981). Power and logarithmic laws are mathematical models, which normally express the change in wind speed with height (WMO 1981, Twidell and Weir 1986). The power law is simpler, adequate and is empirical as compared to the logarithmic law (Aspliden et al. 1986, Farrugia 2002). The power law exponent is strongly dependent on the roughness length and the stability of the atmosphere. The larger the vertical gradient in the wind speed the larger the power law exponent. The exponent typically varies from about 0.1 on a sunny afternoon to about 0.6 during a cloudless night, while over smooth terrain it may be as low as 0.1 and over rough surfaces as great as 0.25 (Dobesch and Kury 2001, Farrugia 2002).

An exponent of approximately 1/7 is commonly used to describe atmospheric wind profiles over the range up to 100 m sufficiently during near-neutral conditions and to low surface roughness and well exposed sites. This value of the exponent has led the extrapolation equation to be called the one-seventh-power law (WMO 1981, Aspliden 1986, Farrugia 2002). The power law exponent is determined using the relation (Twindel and Weir 1986, Aspliden et al. 1986).

$$\frac{V(Z_1)}{V(Z_2)} = \left(\frac{Z_1}{Z_2}\right)^p \qquad (1)$$

where $V(Z_1)$ and $V(Z_2)$ are the mean wind speeds at measurement height Z_1 and new height Z_2 at which the wind speed is predicted, respectively, and *p* is the power law exponent. In wind energy conversion applications the height Z_2 generally corresponds to the hub height of the wind machine.

From equation 1, *p* can be expressed as;

$$p = \frac{\ln\left(\frac{U(Z_1)}{U(Z_2)}\right)}{\ln\left(\frac{Z_1}{Z_2}\right)} \qquad (2)$$

The other method used in estimating the power law exponent is (WMO, 1981; Dobesch and Kury, 2001);

$$p = \frac{\ln\left(\ln\left(\frac{Z_2}{Z_0}\right) \Big/ \ln\left(\frac{Z_1}{Z_0}\right)\right)}{\ln\left(\frac{Z_2}{Z_1}\right)} \approx \frac{1}{\ln\sqrt{\frac{Z_2 Z_1}{Z_0}}} \qquad (3)$$

where *p* depends on roughness length Z_0 in the height range $Z_1<Z<Z_2$.

Before installing a wind turbine at a site, it is necessary to know the actual wind speed and turbulence characteristics at the corresponding height. However, in early stages of prospecting wind energy potential at a site, it may suffice to use the power law exponent because it is rather expensive to take wind speed measurements at levels corresponding to those of hub heights of modern wind turbines. This paper aims at determining the mean power law exponent, which is typical for wind climate of the Southern Highlands of Tanzania by using wind speed data collected at a test site called Makambako. The monthly and diurnal variation of the power law exponent as a function of wind speed is also investigated.

MATERIALS AND METHODS

Test Site and Equipment

The data used in this study were obtained from an automatic weather station installed at Mama Clementina Foundation Secondary School (MCF) southwest of Makambako town in Iringa region, Tanzania. The site is in the southern highland zone of Tanzania ($9^0\ 30^{/}$ S, $34^0\ 50^{/}$ E) at an elevation of about 1685 m above sea level.

Wind speed and direction were measured at 2 m and 7 m above the ground level. The anemometer at 2 m was part of the agro meteorological weather station and the one at 7 m height was about 10 m south-east of the former. The 7 m was the maximum height for which the available mast could reach for wind speed comparison with distance from the ground. Wind sensors were spaced in short distances to avoid errors, which might happen due to rapid changes of wind speeds at lower levels. From the anemometers, wires were connected to the data loggers for data collection. The data were recorded every one-hour and covered the period from 20th May 2002 to 12th February 2003. From the features of obstacles surrounding the site, which were isolated trees with some grass, the roughness length of the area was estimated to be 0.20 m, which is in line with standard values given in WMO, 1981. The other weather parameters like wind direction, temperature, rainfall, air pressure etc. were also measured by the corresponding sensors that were part of the agro meteorological weather station. However, other data were not included in the analysis because the primary objective of the present study was only on wind speed.

Data Analysis

Site-specific values of the power-law exponent *p* were determined using data measured at 2 m and 7 m, and equations 2 and 3. The raw data recorded using data loggers were analyzed using programs like Microsoft Excel and Kaleidagraph. The Microsoft Excel was used to calculate the mean hourly and monthly wind speeds. The calculated hourly power law exponents from the raw data were used to obtain mean hourly, and monthly power law exponents. The mean annual power law exponent was also derived from the mean monthly values. The trends of the variation of hourly and monthly power law exponents with wind speeds were plotted using the program known as Kaleidagraph.

RESULTS AND DISCUSSION

Diurnal variation of the power law exponent

Figure 1, illustrates a marked drop in exponent value during the daytime hours. This trend is in line with what has been reported by other researchers that the power law exponent varies significantly between day and night. Wind shear exponents are on the average much larger between 21 to 08 hours than from 09 to 20 hours. During the night surface cooling is present in which stable conditions prevail and the converse applies for the daytime. On a diurnal basis, wind speeds vary in almost the same way as power law exponent as displayed in Figure 1. The minimum wind speed is obtained at around 13.30 in the afternoon at which the minimum power law exponent is obtained. The figure also shows that a maximum wind speed and a maximum power law exponent are attained at night.

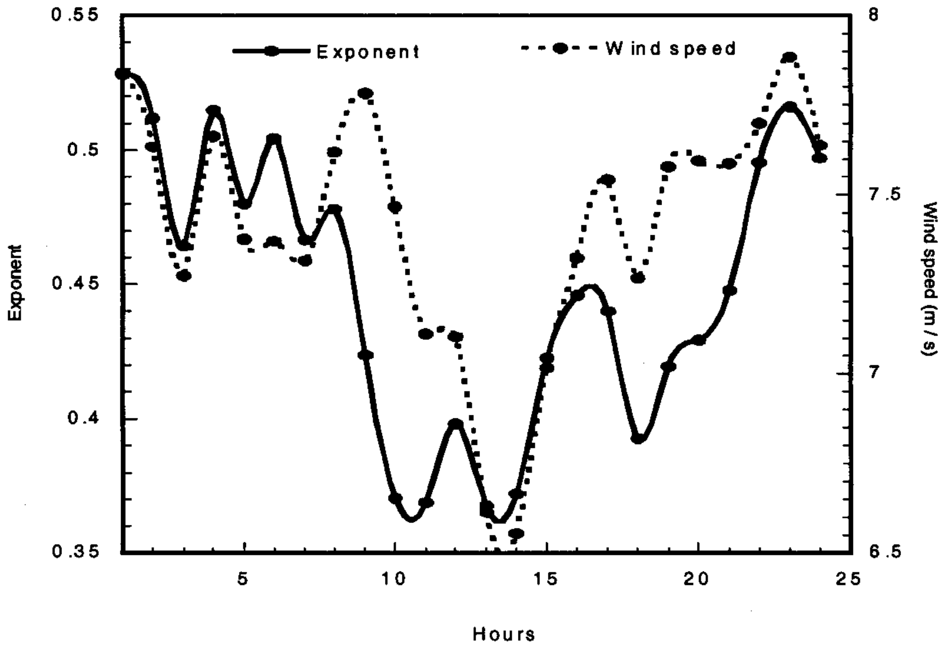

Figure 1: The mean daily wind speed and the mean daily power law exponent

Monthly variation of power law exponent

Examination of the trends of variation of power law exponent was also done on a monthly basis owing to the fact that wind conditions vary throughout the year at a site. Figure 2, which illustrates the mean monthly exponent values for Makambako, shows that lower p values are exhibited from September to December when wind speed is in transition from high to low values. From February to August the power law exponent is comparably high and the wind speed is fairly moderate and this is the corresponding dry season at the assessment site. Changes in the terrain roughness on a seasonal basis around a site have certainly an influence on the variability of the value of the power law exponent. The vegetation of Makambako is characterized by savanna woodland with long grass in which during the rainy period, trees are green while during the dry season plants shed their leaves, a process that increases the porosity of the vegetation. The differences in porosity of the surrounding vegetation have an effect on the roughness length of the surface which in turn has an influence on the calculated value of p as demonstrated by equation 3.

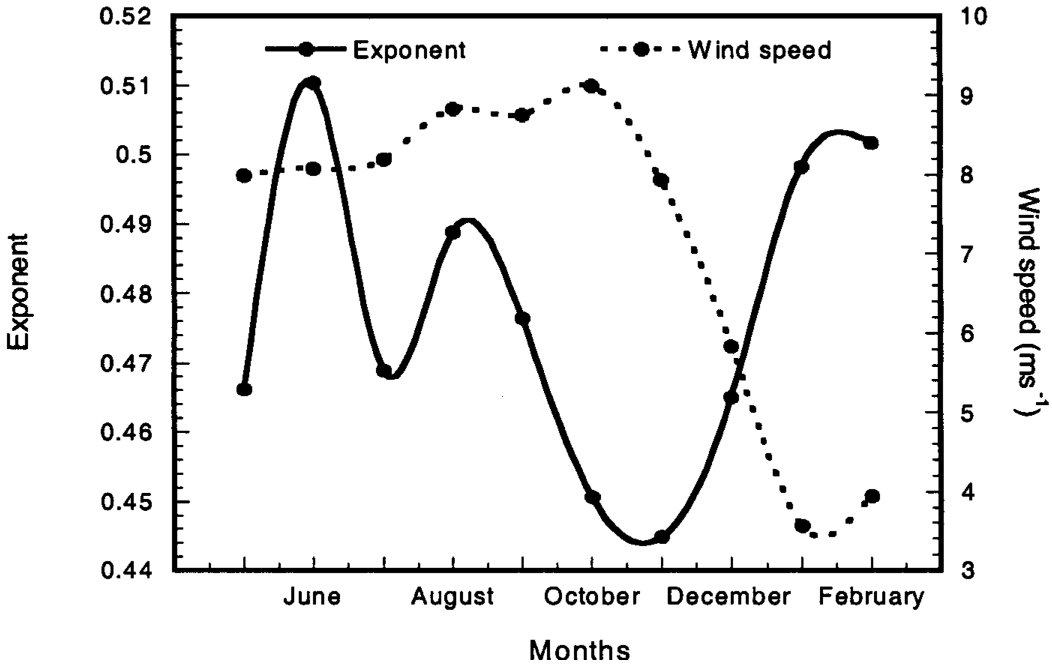

Figure 2: The mean monthly wind speed and the mean monthly power law exponent

The overall power law exponent

The power law exponent obtained from the mean wind speeds gathered at 2 m and 7 m using equation 2 was 0.4729 and from equation 3 was 0.4707. The difference between the two methods was not significant that is 0.47 %. Therefore the overall average value of the power law exponent at the investigation site is 0.47, a value that is substantially higher than 1/7th factor. Using an exponent of 1/7 to extrapolate the 2 m mean wind speed up to 7 m level underestimates the measured mean value at the later height by 34.4 %. The power law exponent so obtained, during this period of investigation, can be used to project wind speeds to higher levels at the test site and other locations that have similar wind climate and topographical features as those of the assessment site.

CONCLUSIONS

The power law exponent shows great variability at Makambako throughout the year. While lower *p* values are exhibited from September to December, from February to August the power law exponent is comparably high. There is also variability of the power law exponent during the day and night in which the *p* values are below the overall mean of 0.47 during the day and higher than the average value during the night. The mean power law exponent obtained at Makambako is higher than the commonly used, that is $1/7^{th}$ power law exponent.

In absence of multiple measurements the use of 0.47 power law exponent for projecting wind speeds from low levels to higher levels will be of value if the topographical and vegetation features are almost the same as that of the site at which the measurements were taken. It is suggested that more researches on determination of the power law exponent at the test site be undertaken to include more parameters like temperature variations with height, pressure gradients and higher levels of wind speed measurements.

ACKNOWLEDGEMENTS
This work was funded through Sida/SAREC to the Faculty of Science, University of Dar es Salaam and technically supported by the Physics Department.

REFERENCES

Aspliden CI, Eliott D L and Wendell LL 1986 Resource Assessment Methods, Siting and Perfomance Evaluation. Physical Climatology for Solar and Wind Energy. In: Guzzi R and Justus CG (eds) Conference Proceedings Miramare - Trieste Itally 21 April – 16 May 1986.

AWEA 1993 Small Wind Energy Systems Applications Guide, American Wind Association, Washington, DC.

Dobesch H and Kury G. 2001 Basic Meteorological Concepts and Recommendations for the Exploitation of Wind Energy in the Atmospheric Boundary Layer, Vienna, Austria (Unpublished).

Farrugia RN 2002 The Wind Shear Exponent in a Mediterranean Island Climate, *Renewable Energy* **28** 647-653.

Twidell J.W and Weir A.D, 1986**,** Renewable Energy Resources, E and F.N Spon Ltd, London.

WMO, Technical Note No. 175 1981 Meteorological Aspect of the Utilization of Wind as an Energy Source. (Edited by C. Aspliden et al) WMO, Geneva.