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EFFECT OF WIND SHEAR COEFFICIENT ON WIND VELOCITY AT COASTAL SITES OF BANGLADESH

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ABSTRACT

In this paper, wind shear coefficient has been determined and analyzed at coastal wind sites of Bangladesh. For searching the wind energy for scale up contribution to renewable energy in rural, pre-urban and urban areas some research work has been done. This is in line with the proposed renewable energy policy of Bangladesh targeting on solar-wind hybrids power generation by renewable energy to meet 5% of the total power demand by 2015. In this work, considering a coastal wind site such as Kuakata where wind shear coefficient has been determined and the effect of wind shear on velocity profile has been analyzed. It is evident that the heating and cooling cycle of the air adjacent to the earth during 24 h of the day influences the wind shear coefficients. During early hours of the day i.e. between 00:00 and 07:00 h, higher and almost constant values of α_1, α_2 and α_3 were observed while from 07:00 h onwards, as heating of the ground surface and the air above it took place, these values started decreasing and after reaching a minimum at 09:00 h remained almost constant up to 18:00 h for α_2. But at 12:00 h the wind shear coefficient becomes minimum both α_1 and α_3. After 16:30 h, the values of α_1 and α_3 again started increasing and after reaching a maximum at 21:00 h showed a decreasing pattern during rest of the night hours, which may be accounted for cooling of the ground surface and the air above it.

Keywords: Wind Shear Coefficient, Mean Wind Speed, Air Density, Solar Wind Hybrid.

1. INTRODUCTION

Wind shear, sometimes referred to as wind shear or wind gradient, is a difference in wind speed and direction over a relatively short distance in the Earth's atmosphere. Wind shear can be broken down into vertical and horizontal components, with horizontal wind shear seen across weather fronts and near the coast, and vertical shear typically near the surface though also at higher levels in the atmosphere near upper level jets and frontal zones aloft. Wind shear itself is a micro-scale meteorological phenomenon occurring over a very small distance, but it can be associated with mesoscale or synoptic scale weather features such as squall lines and cold fronts. It is commonly observed near microbursts and downbursts caused by thunderstorms, weather fronts, areas of locally higher low level winds referred to as low level jets, near mountains, radiation inversions that occur due to clear skies and calm winds, buildings, wind turbines, and sailboats. Wind shear has a significant effect during take-off and landing of aircraft due to their effects on control of the aircraft. An accurate wind resource assessment is an important and critical factor to be well understood for harnessing the power of the wind. It is well known that an error of 1% in wind speed measurements leads to almost 2% error in energy output. Hence precise measurements of wind speed at a site minimize the risk of huge investments. Moreover, the wind measurements are usually made at a height different than the hub-height of the wind machine. The wind speed is extrapolated to the hub-height by using the well-known $1/7^{th}$ wind power law. In fact, the wind speed, at a given site, increases with height by a power factor known as wind shear factor or coefficient. This coefficient is highly dependent on the site where the measurements are made. So, if the wind shear coefficient is greater than 1/7 then wind power law will lead to under estimation of wind speed and hence the wind energy otherwise overestimation. Hence accurate knowledge of wind shear coefficient is essential for actual wind power estimates.

The other important parameter that directly affects the energy production estimates is the air density. The air density depends on the air temperature and the surface pressure of the site of interest. So an assumed value of air density will result into either under or over estimation of energy production. Hence actual air density at the specific site should be obtained using the local temperature and pressure measurements to facilitate accurate energy estimation. The wind shear values are seldom known because the wind speed measurements are made only at one specific height at most of the meteorological data collection stations in the world. There are few locations, mostly in developed countries, where wind speeds are measured at more than one height. Recently, Farrugia [1] presented wind shear coefficients for a Mediterranean island of Malta using wind speed measured at 10 and 25m above ground level. He found that the wind shear coefficient varied with season with a maximum value of 0.45 in January to a minimum of 0.29 in July and August. He also reported higher values during nighttime and lower during daytime. According to Sisterton et al. [2], wind shear coefficients of the order of 0.5 may be found between 30 and 150 m and in extreme case may reach as high as 1.0.

Bailey [3] predicted the vertical wind speed profiles as a function of time of the day and wind speed measured near the ground surface and found that the power law exponent depends on atmospheric stability, wind speed, roughness length, and the height interval. A wind resource assessment study for Texas, USA [4] reported wind shear exponent value in the range of 0.15–0.36 for most of the 17 sites analyzed. Michael et al. [5] calculated wind shear coefficients for 12 Minnesota sites that have been in operation since 1995 or earlier. They found considerable variation (0.2–0.4) in the values of wind shear exponent from location to location. According to Michael [6], higher exponents are usually associated with rougher terrain and taller vegetation or other nearby obstacles. The wind shear coefficients were found to vary from 0.16 to 0.27 at all Iowa Wind Energy Research Institute sites and over all months with an overall average of 0.21 [6].

Rehman and Aftab [10] performed wind power potential assessment for coastal locations in Saudi Arabia. Rehman et al. [11] computed the cost of energy generation at 20 locations in Saudi Arabia using net present value approach. Mohandes et al. [12, 13] used the neural networks method for the prediction of daily mean values of wind speed and concluded that the performance of the neural network model was much better than the traditionally used auto-regression model. Rehman and Halawani [14] presented the statistical characteristics of wind speed and its diurnal variation. The autocorrelation coefficients were found to match the actual diurnal variation of the hourly mean wind speed for most of the locations used in the study. Rehman et al. [15] calculated the Weibull parameters for 10 anemometer locations in Saudi Arabia and found that the wind speed was well represented by the Weibull distribution function. With growing global awareness of the usage of clean sources of energy, wind energy in particular, a lot of work is being carried out in Saudi Arabia, as can be seen from [16–21].

In this work, utilized the wind measurements made at 10, 20, and 30m above ground level to calculate the wind shear coefficients. The site-specific air density was calculated using temperature and pressure measurements made at ground level. The analysis also included the effect of wind shear factor on wind energy.

2. MATHEMATICAL MODEL FOR WIND SHEAR COEFFICIENT AND AIR DENSITY

The wind shear coefficient α was calculated using the following equation –

$$\alpha = \frac{\ln(V_2) - \ln(V_1)}{\ln(Z_2) - \ln(Z_1)} \quad (1)$$

Where, V_1 is the wind speed at height Z_1 and V_2 is the wind speed of height Z_2. This values of α, calculated using equation (1), were used to find the annual, seasonal and half-hourly means value.

The air density was calculated using the following equation–

$$\rho = \frac{p}{RT} \quad (\mathrm{Kg/m^3}) \quad (2)$$

Where, P is the air pressure (Pa or N/m^2), R the specific gas constant for air (287 J/kg ºK) and T the air temperature in degrees Kelvin (º C + 273).

3. DATA DESCRIPTION FOR WIND SHEAR

The overall hourly mean wind speed, temperature, global solar radiation, surface pressure and relative humidity are summarized in Table –1. These averages were obtained using all the data collected over entire data collection period. The last column of Table -1 gives the percentage of data values used in the statistical calculation for each parameter. At 10m above ground level the mean wind speed was found to be 3.19. These averages were obtained using 99.9% of the measured values as shown in the last column of the Table - 1.

At 20 m above ground level the wind speed was 4.23 m/s. In this case, almost 100% of the measured values were used to obtain the mean wind speed. At 30 m above the ground level the wind speed was 4.53 m/s where 100% of the measured values were found to be correct and used in the calculation of its mean. The mean value of wind direction was found to be 10.72º from North. In Bangladesh, temperature varies between a monthly mean minimum of 14 ºC in December and a maximum of 42 ºC in April and May. The mean value of global solar radiation, surface pressure and relative humidity were found to be 393.5 w/m^2 (3.738 kWh/m^2/day), 29.92 inches of H_g and 65.8% respectively.

Table – 1: Overall hourly mean statistics for Bangladesh environment data.

Source: Bangladesh meteorological department, Agarjaon, Shere Bangla Nagar, Dhaka-1207.

Parameters	Unit	Min^m	Max^m	Mean	% of value
Wind speed (10 m)	m/s	0	44.63	3.19	99.9
Wind speed (20 m)	m/s	0	73.09	4.23	100
Wind speed (30 m)	m/s	0	88.10	4.53	100
Wind direction(N)	o	0	255	10.72	100
Temperatur e	º C	14	42	26.1	99.6
Global solar radiation	W/m^2	0.1	1039.4	393.5	100
Pressure	of Hg	29.53	30.35	29.92	76.6
Relative Humidity	%	20	81	65.8	99.68

The detailed discussion on the result is presented in terms of annual, seasonal and diurnal variation of wind shear coefficient and air density in the forthcoming paragraphs.

4. CHARACTERISTICS OF WIND SHEAR

The wind shear coefficients were calculated using Equation (1) and three pairs of wind speeds on each side of the wind measurement mast. The wind shear coefficients calculated between 20 and 10, 30 and 20, and 30 and 10m using wind speed pairs WS2 and WS1, WS3 and WS2, and WS3 and WS1 were designated as α_1, α_2, and α_3, respectively. The long-term (one year) averages of these three coefficients are summarized in Table – 1.

Table – 2: Wind shear coefficient calculated using 10 min mean value of wind speed at different height.

From above Table – 2: the average value of α_1 was 0.407.

Wind shear between	Based on annual mean wind speed
α_1 – 20 m and 10 m	0.407
α_2 – 30 m and 20 m	0.169
α_3 – 30 m and 10 m	0.319

It was obtained using annual mean wind speeds WS2 and WS1. The mean wind shear coefficient between 30 m and 20m was 0.169 while between 30 m and 10 m it was 0.319. The smaller values of α_2 in Table –2 conforms to the fact that at higher altitudes the surface effects tends to minimize due to better mixing and lesser surface effects. The wind shear coefficients were calculated for Kuakata using yearly mean values of wind speeds.

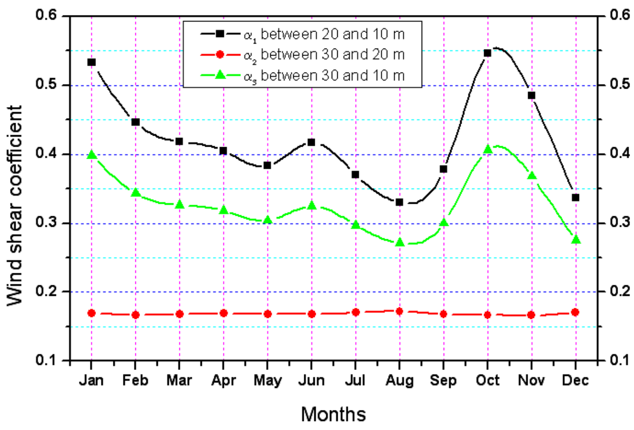

Fig 1. Monthly variation of wind shear for Kuakata, Bangladesh using 10 min durational mean wind speed values from January to December.

The seasonal variation of wind shear coefficients has shown in Fig. 1. Relatively higher values of α_1, α_2 and α_3 coefficients were observed during January – April and October – November compared to those during rest of the months. As seen from Fig. 1 values of α_1 were the highest, α_2 the smallest and α_3 lied in between the two. Maximum values were observed in the month of October while the minimum in August. This conforms to the physical reasoning that during summer time the temperature are higher and hence better mixing of the air takes place above the ground, which results into smaller values of shear coefficients. On the other hand, during winter time, the air above the ground experiences less mixing due to lower temperatures and hence higher values of wind shear coefficients. Durational variation of wind speed has been shown below-

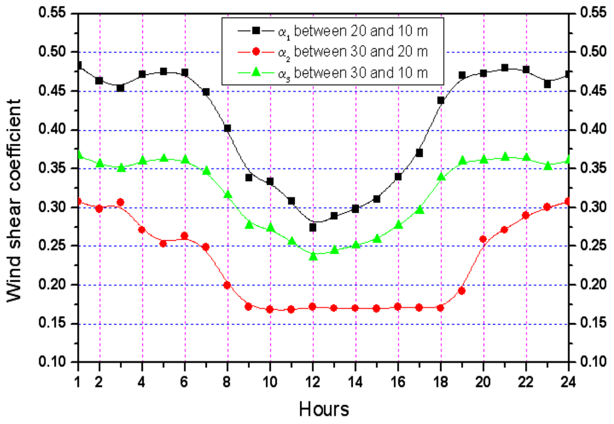

Fig 2. Diurnal variation of wind shear for Kuakata using hourly mean values of wind speed at different height.

In order to study the diurnal pattern, hourly mean values of wind speeds were used to obtain the wind shear coefficients $\alpha_1 - \alpha_3$. The diurnal variation of wind shear coefficient α_1, α_2 and α_3 are shown in Fig. 2. From these figure, it is evident that the heating and cooling cycle of the air adjacent to the earth during 24h of the day influences the wind shear coefficients. During early hours of the day i.e. between 00:00 and 07:00h, higher to decreasing values of α_1, α_2 and α_3 were observed while from 07:00 h onwards, as heating of the ground surface and the air above it took place, these values started sharply decreasing and after reaching a minimum at 09:00h remained almost constant up to18:00 h for α_2. But at 12:00h the wind shear coefficient becomes minimum both α_1 and α_3. After 16:30h, the values of α_1 and α_3 again started increasing and after reaching a maximum at 21:00h showed a decreasing pattern during rest of the night hours, which may be accounted for cooling of the ground surface and the air above it.

5. AIR DENSITY CHARACTERISTICS

The air density is an important parameter whereas wind power density calculation is concerned. The wind power density is directly proportional to the air density. Denser the air, the higher is the wind power density and vice versa. In the research work, the air density was calculated using the measured values of temperature and pressure recorded near ground surface every half hour over the entire period of data collection. The mean values of air density at different heights are given in Table – 3. At all heights these values varied between a minimum 1.12 kg/m^3 and a maximum of 1.25 kg/m^3 while the mean remained as 1.18 kg/m^3.

Table – 3: Mean air density for Kuakata at different height.

Height	Air density, ρ (kg/m^3)		
	Min^m	Max^m	Mean
At 10 m	1.12	1.25	1.18
At 20 m	1.12	1.25	1.18
At 30 m	1.12	1.25	1.18

The air density at winter time was found to be relatively higher compared to summer months. The overall mean value of air density at Kuakata was found to be 1.18 kg/m^3 and is recommended to be used for all practical purposes. The air density was found to vary very slightly during day and night cycle. Slightly higher values were observed during night and early morning hours compared to those during day light hours.

6. WIND ROSE

A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Historically, wind roses were predecessors of the compass rose (found on maps), as there was no differentiation between a cardinal direction and the wind which blew from such a direction. Using a polar coordinate system of gridding, the frequency of winds over a year period are plotted by wind direction, with color bands showing wind ranges. The directions of the rose with the longest spoke show the wind direction with the greatest frequency. Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions over a whole year period. The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. A wind rose plot may contain additional information, in that each spoke is broken down into color-coded bands that show wind speed ranges. Wind roses typically use 16 cardinal directions, such as north N, NNE, NE, ENE, etc., although they may be subdivided into as many as 32 directions. In terms of angle measurement in degrees, North corresponds to 0°/360°, East to 90°, South to 180° and West to 270°.

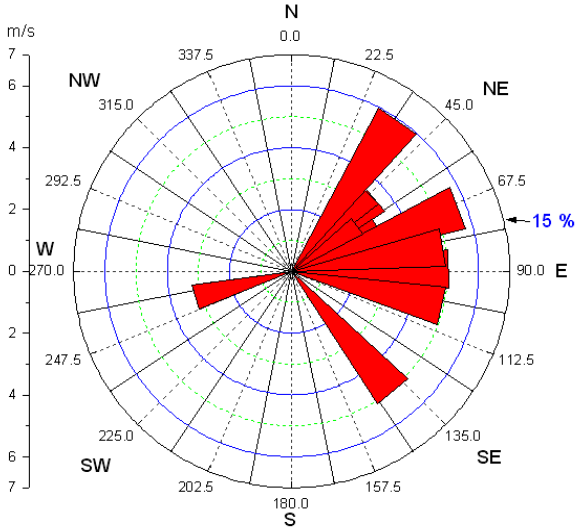

Fig 3. Typical Wind rose for Kuakata.

A typical polar diagram of annual wind duration from different directions has shown in Fig. 3, which is known as wind rose. In the wind rose, each radial line is proportional in length to the percentage of time that the wind blows along the line. Every circle represents percentage of total time and the line head touches the circle of vertical scaled of mean wind speed in m/s for that direction. The total length of the lines adds up to 100 percent. For Kuakata wind direction varies from NNE to SE i.e. 25º to 140º except December. In December, wind blows from WSW i.e. 255º with velocity 3.22 m/s. A wind rose may also be drawn for 8 or 16 sectors, but 12 sectors tend to be the standard set by the European Wind Atlas. But in this research use 16 sectors for a wind rose.

7. DISCUSSIONS

For monthly variation of wind shear, it has been seen that the value of wind shear has remarkable variations both for α_1 and α_3 because these is the rougher wake zone and the wind shear is too high. But between 30m to 20m wind shear variation becomes almost constant because, it just above the wake zone. In the cause of diurnal variation of wind shear, its value becomes min^m at 12:00h both for α_1 and α_3 because the air adjacent to the earth surface becomes wormer but for α_3, the wind shear almost constant from 10:00h–18:00h because this is the adjacent of weak zone and at this time temperature variation above 30m was too low. From these figure, it is evident that the heating and cooling cycle of the air adjacent to the earth below 30m height during 24:00h of the day influences the wind shear coefficients. The wind shear coefficient also affect on wind velocity or velocity profile of a site in different height.

8. CONCLUSIONS

In regard to the present data analysis, the following conclusions are drawn:

- The monthly mean variation of wind shear was higher at two reasons i) January to April and ii) October to November and their values were above 0.40.
- The value of wind shear is higher between 10m and 20m height and lower between 20m and 30m height.
- The effect of heating and cooling cycle of the air adjacent to the earth during 24h of the day follow a distinct pattern which is clearly shown in the diurnal variation of wind shear curve.

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10. NOMENCLATURE

Symbol	Meaning	Unit
α	Wind shear coefficient	
V_1	Velocity at height Z_1	(m/s)
V_2	Velocity at height Z_2	(m/s)
Z_1	Reference height at 10m	(m)
Z_2	Height from the ground	(m)
ρ	Air density	(kg/m^3)
P	Air pressure	(Pa)
R	Specific gas constant for air	(J/kg^{o}K)
T	Air temperature in degree Kelvin	(^{o}K)

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