Determination of Wind Shear Coefficients and Conditions of Atmospheric Stability for Three Iraqi Sites

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Abstract: The coefficient of wind shear at low and high frequencies, from diurnal and seasonal variations to disturbance caused by weather patterns, is subject to temporal fluctuations, but in many cases, the coefficient of wind shear assumed as a constant. This presumption causes major resource management errors, raises instability in projects and potentially affects the ability to control the wind turbines connected to the grid. Hourly average of 10 m wind speed with a standard (50 m) height employed to estimate the WSC with the well-known power equation for the wind profile law. This paper estimates WSC from wind speed data on three sites in Iraq. Monthly wind speed and wind direction changes were determined for these locations. The variations of WSC in one year are (0.23, 0.2, and 0.35) for Al-Shehabi, Al-Najaf, and Al-Fajer respectively. In the summer months (June to September) it is obvious that average wind speeds in all select areas increase while in other seasons they are almost decreasing. The WSC had neural diurnal and monthly variations. Due to the increased temperature at this period of year, WSC has decreased at mid-day, and this is valid for all studied site during the winter and summer days. The stability of atmosphere conditions was determined as stable, stable, and strongly stable for Al-Shehabi, Al-Najaf and Al-Fajer sites respectively.

1. Introduction

Wind energy, as it is clean and sustainable, is one of the major sources of renewable energy and is witnessing a great increase in the world due to the increase in energy demand. Also, it is one of the ways to reduce fossil fuel dependence as well as to face global warming [1]. Iraq is one of the countries that started investing renewable energy for multiple purposes, including in the field of irrigation by installing hybrid systems in southern Iraq. There are many studies and research that dealt with the study of some areas in central and southern Iraq, for example see [2,3,4,5,6]. Complementing the previous studies and to demonstrate the effect of shear parameter on wind studies, the current research will address a description of the behavior of this parameter monthly and annually and for three regions of Iraq at different heights. Due to its profound influence on power density, wind shear is a key considering factor in height [7]. The wind shear coefficient WSC symbolized as (\alpha) can be calculated by a famous empirical formula called the power law, which represents an extrapolation of wind speed at a specific location and certain altitudes as in the following equation [8,9]:

\[
\frac{v_2}{v_1} = \frac{Z_2}{Z_1}^\alpha
\]
Where: \( \alpha \) is the WSC (exponent), \( v_1 \) = wind speed (m/s), at the lower height \( Z_1 \) (m), \( v_2 \) = wind speed (m/s), at the upper height \( Z_2 \). The second law on wind speed extrapolation is the logarithmic law [9]:

\[
v(z) = v_R \frac{\ln \frac{z}{Z_0}}{\ln \frac{z}{z_R}}
\]

(2)

Where, \( Z_0 \) is a roughness length (typically 0.01 m). Note that \( v_R \) (i.e. value \( v \) at 10 m) will pass both curves at \( Z = Z_R = 10 \) m, both need a match between \( \alpha \) or \( Z_0 \) parameter. Wind shear is caused by friction between wind and surface roughness [10]. Therefore, it depends on the surface roughness as well as the stability of the atmosphere which is affected by temperature stratification that causes shear variations by the hour, month, and season [11, 12]. Wind shear causes turbulent flow and slows down the wind speed to zero directly at ground level [13]. Then, if a wind turbine is installed at a specific site, it needs to have an adequate hub height to prevent the wind shear effects. In wind energy calculation wind speed plays an important role in particular at hub height altitude. Therefore, when the value of the wind shear coefficient is known, wind speed must be calculated by a Power Law. At the steady atmospheric conditions and flat area, \( \alpha \) is considered as 1/7 [14]. Interestingly, high values of \( \alpha \) refer to a rapid change of wind speed with height [15]. The coefficient of wind shear is not constant; it changes with stability and surface roughness. Table 1 shows the values of \( \alpha \) for different types of the area [16, 17].

Table 1. Exponent for the WSC’s in different areas [18]

| Area type                                                   | \( \alpha \)   |
|------------------------------------------------------------|----------------|
| Smooth hard ground, calm water                             | 0.10           |
| Short grass on untilled ground                             | 0.14           |
| Level country with foot-high grass, occasional tree       | 0.16           |
| Tall row crops, hedges, a few trees                       | 0.20           |
| Many trees and occasional buildings                       | 0.22 – 0.24    |
| Wooded country – small towns and suburbs                  | 0.28 – 0.30    |
| Urban areas with tall buildings                            | 0.4            |

However, a lot of projects have been carried out to estimate \( \alpha \) at different sites by using the power law or its modification using various simulations and models [19, 20, 21]. Threshold of WSC can be classified according to [22], there are five classes of atmosphere stability, and one of them is depending on WSC value as shown in Table 2.

L: Obukhov length, \( \alpha \): wind shear coefficient, IUcup: horizontal turbulence intensity from cup anemometers, IU1 SODAR: horizontal turbulence intensity from SODAR, TKE: turbulence kinetic energy.

Mean wind speed given by equation 4:

\[
\bar{v} = \frac{1}{N} \left( \sum_{i=1}^{N} v_i \right)
\]

(3)

In this study, wind shear coefficient (\( \alpha \)) and average wind speed of three sites was calculated according to the power law. Finally, the stability of atmospheric conditions for these sites can be classified according to [22].

2. Data Description

One-year available data set (2016) has been collected from a met mast installed in each site with 50m height. The mast installed by the ministry of science and technology. The time period between the record and the next is 10 minutes. This data is analyzed to calculate the wind shear coefficient (\( \alpha \)).
3. Sites Locations and Descriptions

Three sites have been selected to study in this paper as listed in Table 3. The locations of these sites are shown in the Figure 1.

| Site                  | Longitudinal (Degree) | Latitudinal (Degree) | Site Elevation (above surface level m) |
|-----------------------|-----------------------|----------------------|----------------------------------------|
| Al-Shehabi            | E: 46 24.551          | N: 32 46.389         | 46                                     |
| Al-Najaf              | E: 44 18.330          | N: 31 40.921         | 51                                     |
| Al-Fajer              | E: 44 71.355          | N: 31 51.193         | 13                                     |
4. Results and discussions

Average wind speed values were determined at 10 m and 50 m height. Figures (2-4) demonstrate the monthly variations of such values in the selected locations. In the summer months (June to September) it is obvious that average wind speeds in all select areas increase while in other seasons they are almost decreasing.

Figure 5 provides the annual analysis of the mean wind speed of studied locations.

Figure 2. Monthly wind speed variation at Al-shehabi site  
Figure 3. Monthly wind speed variation at Al-Najaf site  
Figure 4. Monthly wind speed variations at Al-Fajer site
Figure 5. The annual wind speed values at the sites under study

When the wind speed in a specific location is analyzed for any reason, a precise description of all the directions at that site must be founded. With the Wind Atlas Analysis and Application Program (WAsP), the wind direction for the interesting sites has been determined. Figures 6-8 illustrate the wind direction for each site.

Figure 6. wind rose for Al-Shehabi site
Figure 7. wind rose for Al-Najaf site
Figure 8. wind rose for Al-Fajer site

Obviously, for these places, the north-west is the prevailing direction. The three sites have calculated wind shear coefficients and drowned in curves. Based on the power law the calculations depend, the mean wind speed was measured at 10 m and 50 m and was used to get the monthly values of (α) in this formula. Two extreme days, a winter day (1 January), and a summer day (1 July) were taken into consideration. Figure 9 shows the WSC variations in Al-Shehabi every day and month.

It is clear from figure 9 that the variation of WSC in one year was 0.23. During winter the WSC is higher due to the air mixing above ground level. Diurnal WSC variability was decreased by the warming of the ground surface by the sun from 0.00 to 5.00 h and gone up and down from 5.00 to 15.00 h. From 15.00 to 24.00h the WSC increased because of surface cooling. Figure 10 represents the daily and monthly behavior of WSC at Al-Najaf site, Figure 10 indicates that the WSC variance was 0.20 in one year. In the winter season, the WSC is higher. During night hours the WSC was reached maximum whereas it lowered during daylight hours.
Figure 11 represent the daily and monthly behavior of WSC at Al-Fajar site. Due to the complex landscape (region contains various geographical features such as residential neighborhoods and agriculture areas), the variability of WSC was 0.35 per year. Figure 12 is shown the annual value of (α) at these three sites.

Figure 9. The variations of WSC in Al-Shehabi site, (a) daily variations, (b) monthly variations

Figure 10. The variations of WSC in Al-Najaf site (a) daily variations, (b) monthly variations

Figure 11. The variations of WSC in Al-Fajar site (a) daily variations, (b) monthly variations
5. Conclusions

Based on one year of wind speed data in three metrological stations in Iraq, the WSC had neural diurnal and monthly variations. In the daily behavior of WSC, it is decreased at the midday and around due to the increasing of temperature at this period of the day, this is valid at the winter day and summer day at all the studied sites. The atmospheric stability condition at the sites of the studied locations can be concluded for Al-Shehabi, Al-Najaf and Al-Fajar as (stable, stable, strongly stable) according to the WSC values and compared to the threshold criteria as mentioned in table2.

6. References

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