Choosing of relevant low height for operation wind turbine over urban Baghdad city

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Abstract. Two different sets of data used to achieve this work were measured by fast- and slow-response devices, which located on the roof of building followed to College of Science, Mustansiriya university. Wind speed data classified to calculate their frequencies and wind rose. Wind direction prevailing is northeast and most frequencies are at less than 3 m/s. To improve these speeds, the internal boundary layer (IBL) height establishing over urban Baghdad city was estimated to satisfy the airflow characteristics before entering the city. The values of IBL height were calculated according to air stability classifications: unstable, neutral and stable. These values are lower at stable, graduate increase at neutral, and extreme increase at unstable conditions. However, the better performance of wind turbine operation over the surface of Baghdad city is suggested to be at the low level of 78 m.

1. Introduction
All non-(and developed) countries depend on the existence of energy either directly or indirectly. A feasibility study of any wind energy project should certainly involve a study of the spatial, temporal, and directional variations of wind speed. In order to optimize wind energy conversion systems and maximize the energy extraction frequency distributions of variations are required [1]. Knowledge of the wind characteristics and variability in the lower of the atmosphere is important to, for example, exploitation of wind energy, planning of tall buildings, and monitoring of dispersion of pollutant substances. For example, in the field of energy production, these characteristics where wind turbine installations are planned are critical. A comprehensive review of the main issues related to the assessment and forecasting of the wind and wind energy has been shown by Koracin et al. [2]. The aim of this paper focuses on analyzing the wind speed and wind direction distributions, as well as estimating the IBL depth, which can be considered as lower height for installing wind turbine in urban boundary layer of Baghdad city.

2. The theoretical frame
Figure 1 shows that a complicated flow system developing above such an inhomogeneous surface. The reason is that over each surface a wind profile is generated dependent on the surface roughness. Due to the horizontal wind field, the different profiles are shifted downwind forming a layer of discontinuity, which is called an internal boundary layer (IBL). Therefore, neighboring areas can also affect the
exchange of energy and matter above a different downwind area. The IBL is caused by different surface roughness and different source areas of surface temperature, moisture, etc. Consequently, IBL can also be found for neutral, stable, and unstable stratifications. Thus, the study of IBL is very important in the use of wind power [3].

The distance (X) downwind from a change in surface features is called fetch. In other speech, it is the distance between the search area and the city influential limits in the wind flow. When making surface-layer measurements, it is desirable to locate the instrument mast far enough downwind of the border so that the depth of the IBL is greater than the height of the mast. Thus, with large fetch, the surface-layer measurements are necessary to observe characteristic of the local field in which the instruments are located. For this reason, many measurements are made within large uniform farm fields, meadows, land, or forests [3].

The height of the internal boundary layer, $H_{IBL}$, developing from rough-to-smooth transition can be estimated by the equation [4]:

$$
\frac{H_{IBL}}{z_0} = 0.3 \left( \frac{X}{z_0} \right)^{\alpha}
$$

where $z_0$: surface roughness length in (m). The exponent $\alpha$ is constant based on stability class: $\alpha$~0.8 for neutral, ~0.6-0.7 for stable, and larger ~0.8-1.0 for unstable conditions [4].

Atmospheric stability has great importance in determining the wind flow and the logarithmic relationship of winds with altitude. It depends on both wind speed and lapse rate changes. Here the stability parameter was calculated by using local Obukhov length, $\Lambda$, follow as [5]:

$$
\Lambda = -\frac{u^3}{\kappa g \bar{w} \bar{T}}
$$

where $\bar{w} \bar{T}$: sensible heat flux with $w'$ (vertical fluctuation of wind $= w - \bar{w}$) and $T'$ (The vertical temperature, $T' = T - \bar{T}$), $\bar{T}$: Average air temperature (in Kelvin), $\kappa$: von-kármán constant (~0.4), g: Accelerating gravity, $u_*$: Friction velocity ($u_* = \sqrt{|-u'\bar{w}'|}$) with $u' = u - \bar{u}$ is the longitude fluctuation of wind. The wind changes logarithmically with altitude, and the equation below is applied to describe the velocity of the wind at different altitudes [6]:

$$
U(H_{IBL}) = U(H_{ref}) \left( \frac{H_{IBL}}{H_{ref}} \right)^{\beta}
$$

where $U(H_{ref})$ is reference wind speed at height $H_{ref}$ and $U(H_{IBL})$ is the wind speed at height $H_{IBL}$. The power $\beta$ is based on the experimental data and dependent on the surface roughness and air stability. The values of $\beta$ are 0.15 for the unstable, 0.25 for neutral and 0.3 for the stable conditions [7]. The wind power density (WPD) available from moving is proportional to how much wind passes the wind turbine, i.e.,

$$
WPD = \frac{1}{2} \rho A U^3
$$

where $A$ is the airflow cross-section area and $\rho$ is the air density (1.27 kg/m$^3$).

3. Site and data
In this work, two different sets of data were used: fast-response wind components (u, v, w) and temperature measured by 3D ultrasonic anemometer, and slow-response wind speed and its direction measured by the automatic weather station. These devices are located on the roof of building of atmospheric science department with 19 and 18 m height respectively above the ground level. For first set data, 30 days were available dispersed during six months of the year, 2016. They are sampled every second with frequency 1 Hz. The dates of these data were 4-5-6 Feb., 1-6-7-8-23 Mar., 8-9 May, 15-22-24-25 June, 5-7-8-9-10-13-14-15-22-23-27-28-30 July and 2-5-6 Aug. with total number 223 runs. The weather situations for these days and the certain observation hours (00-01, 05-06, 09-12, 15-18, 21-00) were clear sky. We took the sample length of a quarter of an hour.

Slow data were recorded for every hour of 2016, except for the last two months (Nov. and Dec.) because of no available and sometimes they observed for a quarter of an hour in some months. However, the total runs received are 15591, which we cannot get it from the first station (fast-response data). We used some programs such as Excel, Matlab and Origin version 9.3 to execute this work.

4. Results and discussion

4.1. Wind speed and it direction distributions

We could make a classification of the data taken from the automatic station by using the Matlab program to 10 intervals as shown in Table 1, and also used to know the average wind speed for each interval according to the classification to the initially identified. Although highest frequencies of wind are in the first three intervals, the wind speed with values higher than 3 m/s has good frequencies that can move turbine blades to produce electricity.

It can also see from Table 1, most frequencies (about 75%) are for low values of wind velocity, while about 25% of high values of wind are available over the site. The wind power densities per unit area were also calculated from equation (4) for each mean wind velocity as reported in last column of Table 1, in which the first three values of WPD are not convenient for generating electrical power, but they are accelerated up at increasing wind.

Table 1: The frequency of wind speed for ten intervals of wind speed.

| U intervals (m/s) | U̅ (m/s) | No. of runs | Percent freq. (%) | PWD (W/m²) |
|-------------------|---------|-------------|-------------------|------------|
| 0-0.9             | 0.6     | 4053        | 26.0              | 0.1        |
| 1-1.9             | 1.5     | 4159        | 26.6              | 2.1        |
| 2-2.9             | 2.4     | 3672        | 23.5              | 8.7        |
| 3-3.9             | 3.3     | 2270        | 14.6              | 22.6       |
| 4-4.9             | 4.2     | 1038        | 6.7               | 46.7       |
| 5-5.9             | 5.3     | 97          | 0.6               | 93.8       |
| 6-6.9             | 6.3     | 165         | 1.1               | 157.5      |
| 7-7.9             | 7.2     | 78          | 0.5               | 235.1      |
| 8-8.9             | 8.2     | 49          | 0.3               | 347.4      |
| 9-9.9             | 9.4     | 10          | 0.1               | 523.3      |
| **Sum**           | **15591** |             | **100.000**      |            |

To display information on the wind speed and its direction, they are combined in a diagram of a wind rose, which illustrates the distribution of wind in different directions and is useful in determining the prevailing trend of wind through the diagram and also mission in the design of wind farms and urban planning [8]. The chart was divided into 16 sectors. Wind rose defines the percentage of time that we get wind from a particular direction as well as repetition of wind direction. The wind velocity and its direction data taken from automatic weather station are plotted by Origin software to produce the wind rose as shown in Figure 2. The trend was calculated and found that the prevailing wind
direction is northeast and east-north-east. The impact of high roughness elements surrounding the site has been changed the prevailing winds from northwest [9].

4.2. Wind power density at IBL height

To calculate fetch from the university site at eight directions according to the regions depending on the change of the region roughness including height of buildings and trees and density of buildings that work on the obstruction of the wind, it has been taken into account and by using Google earth map to surrounding the study site (see Figure 3), in which the numbers in (km) represents the fetches estimated from surface roughness change to the measurement site. Mean surface roughness length for Bab Al-Muadam area, ($\overline{z_0}$~1.2 m) was adapted as reported by Al-Jiboori and Al-Draji [10]. Before estimating IBL height, air stability was computed using equation (2) to determine the $\alpha$ value. Then the IBL height was calculated by equation (1). The results of height of IBL were found to be largest under unstable conditions as shown in table 2, while their values were lowest under stable conditions.

Figure 2. The wind rose diagram for study area.  
Figure 3. Map of Baghdad city on which red lines and numbers are fetch values.

We estimated the wind velocity using equation (3) at IBL heights in different stability conditions (unstable, neutral and stable) and then found the average of wind speed for height as shown in table 2, where the initial height of the station ($H_{ref}$) is about 18 m and the second height ($H_{IBL}$) is estimated as illustrated in table 2, while the wind speed data ($U_{ref}$) obtained from the automatic weather station.

Table 2: The heights of IBL and wind speeds at them under different stabilities.

| Dir. | $U_{18}$ (m/s) | Unstable class | Neutral class | Stable class | $U_{IBL}$ (m/s) | WPD (W/m$^2$) |
|------|----------------|----------------|---------------|--------------|----------------|----------------|
| N    | 0.6            | 108 (m) 0.8    | 108 (m) 0.9   | 37 (m) 0.7   | 0.8 (m) 108     | 0.3            |
| NE   | 1.5            | 153 (m) 2.1    | 284 (m) 1.7   | 284 (m) 1.7  | 2.0 (m) 284     | 5.0            |
| E    | 2.4            | 223.7 (m) 3.5  | 38.6 (m) 3.0  | 38.6 (m) 3.0 | 3.4 (m) 38.6    | 24.8           |
| SE   | 3.3            | 298 (m) 5.0    | 46 (m) 4.4    | 46 (m) 4.4   | 4.9 (m) 46      | 74.1           |
| S    | 4.2            | 569 (m) 7.1    | 73.5 (m) 6.4  | 73.5 (m) 6.4 | 7.2 (m) 73.5    | 235.1          |
| SW   | 5.3            | 484 (m) 8.7    | 65.5 (m) 7.8  | 65.5 (m) 7.8 | 8.8 (m) 65.5    | 429.3          |
| W    | 6.3            | 1410 (m) 12.1  | 77.9 (m) 9.8  | 77.9 (m) 9.8 | 11.4 (m) 77.9   | 933.3          |
| WN   | 7.2            | 436 (m) 11.6   | 68 (m) 10.7   | 68 (m) 10.7  | 11.8 (m) 68     | 1035.1         |


The average wind speed calculated at the IBL heights does not exceed 25 m/s, which cannot damage the wind turbine, which leads to a mall function or defect in the work of the turbine and therefore the speed is suitable for the installation of a wind turbine. The improvement of wind values at measurement site, surely, will be clear when calculating them at IBL height using equation (3) for all stability conditions as presented in table 2. For example, $U = 2.4$ m/s for interval (2-2.9) m/s had been approximately 3.5 m/s for different stabilities. This means the wind velocity increased about 50 percent and could reach about 60 percent at upper remaining levels.

The improvement in WDP is also occurred in all mean wind velocities as shown in the last column of table 2, except the first two values. Also, it should notice that these values are better than those corresponding reported in table 1. The lowest IBL height that equals 78 m for neutral segment as average height is the best lowest for setting wind turbine for Mustansiriyah university. The neutral stratification can be considered as moderate state and also is not unstable nor stable stratification. It can be considered as transition state between in(-stability) classes.

5. Concluding remarks

Through data collection of wind speed and its direction for the year 2016 and its analysis in according to the different stability conditions that accompanied the data recording by using different devices mount on the roof of one of buildings belong to Mustansiriyah university. With changing roughness surface around the site, internal boundary layer height that is corresponding to estimate the minimum height for settling up the wind turbine over urban Baghdad city. The concluding remarks can be summarized as:

1. From wind speed frequencies, 75% of the wind speed ($<3$ m/s) are not encouraged to set up wind turbine due to the site is affected by tall buildings and trees.
2. Because high surface roughness, the prevailing wind direction was changed from north or northwest to be northeast.
3. To eliminate surface roughness effect, internal boundary layer depth was estimated, thus the suggestion height for best operation of wind turbine is at neutral condition (as an average) to generate wind energy at the university site is about 78 m.

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