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Relative Humidity Effect on the Extracted Wind Power for Electricity Production in Nassiriyah City

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Abstract

The relative humidity effect on the wind power was extracted as a renewable energy for electricity production in Nassiriyah city - south of Iraq investigated for three years (2011-2013) by theoretical calculations. The study showed that the effect of relative humidity on the annual average of extracted wind power at the minimum altitude which is feasible for electricity production in this city (32 meter for α = 0.4 and 44 meter for α = 0.3) is limited, but it increase with the altitude to be noticeable at high altitude. The percentage loss on the annual average of power for moist air (due to relative humidity effect) uneffective and vary between (0.847% and 1.106%) at altitudes (15 m and 71 m) respectively.

Keywords: Physics; Renewable energy; Wind energy

Introduction

The temperature and humidity are important climatic variables that effect on the wind power [1,2]. The previous paper [3] studied the temperature effect on the extracted wind power as a renewable energy in Nassiriyah city (in Iraq) which is located at 31 (east) with 46 (north) intersection lines. This paper is focusing on the study to simulate the relative humidity effect on the extracted wind power in this district. The results are necessary to complement obtained results in reference [3] because of near the district location from Euphrates river, marshes and Shutt Al-Arabe, which make sometimes humid climate features in Nassiriyah city. No data of relative humidity reported at different altitudes in the district just that measured at 10 meter elevation [4]. Software program prepared in this study to compute the relative humidity and investigate its effect on wind power as a function of altitude.

Theory

According to the ideal gas law, a cubic meter of air has a certain number of molecules, and each of those molecules has a certain weight. Whenever water vapour molecules are added to the air, they displaces some other molecules in the volume of air. Nitrogen molecule is the most abundant in the air molecules, and it has an atomic weight approach to 14, then the molecules have a weight (atomic mass) approach to 28. For oxygen, the N_2 atomic weight is 16, so an O_2 molecule has a weight of 32. Hydrogen has an atomic mass of 1, so the molecule of H_2O has a weight of (1+1+16=18). Hence the water molecule is lighter in weight than either the nitrogen molecule or oxygen molecule. Therefore, the volume of air that contains some water molecules will be weight less than the same volume of air without water molecules. This lead to decrease density which means that the moist air has less density than dry air at the same temperature [1,5]. Water is extremely found pervasive in the air as vapour. Humidity is the quantity of water vapour present in air, and there are many varied ways of expressing it such as an absolute humidity, specific humidity, and relative humidity. Relative humidity is the amount of water vapour in the air relative to the maximum amount possible, thus it is at all temperatures and pressures defined as the ratio of the water vapour pressure to the saturation water vapour pressure, and it is defined mathematically by the following expression [6-8].

$$RH = \frac{e_a}{e_s(T)} \times 100\% \qquad (1)$$

Where RH is the relative humidity, e_a is the actual water vapour pressure, it is contributes to the total atmospheric pressure, defined by the Antoine equation [9].

$$\log_{10} e_a = A - (\frac{B}{C+T}) \qquad (2)$$

Where $A = 8.07131$, $B = 1730.63$, $C = 233.426$, e_a is in mmHg (1mm Hg=133.322 Pascal), T is the temperature in degrees Celsius (C°). $e_s(T)$ is the saturation vapour pressure (Pascal) at the same temperature (T), When air enclose above an evaporating water surface, an equilibrium is reached between the water molecules escaping and returning to the water reservoir. At this moment, the air is saturated since it cannot store any extra water molecules. Many algorithms for determining the saturation vapour pressure [10,11]. Herman Wobus developed Albeit formula for determining saturation vapour pressure [1,12] as the following expression.

$$e_s(T) = \frac{e_{s0}}{p^8} \qquad (3)$$

Where,

$$e_{s0} = 6.1078$$

$$P = (C_0 + T*(C_1 + T*(C_2 + T*(C_3 + T*(C_4 + T*(C_5 + T*(C_6 + T*(C_7 + T*(C_8 + T*(C_9)))))))))),$$

$$C_0 = 0.99999683 \qquad C_1 = -0.90826951E-02$$

$$C_2 = 0.78736169E-04 \qquad C_3 = -0.61117958E-06$$

$$C_4 = 0.43884187E-08 \qquad C_5 = -0.29883885E-10$$

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$$C_6 = 0.21874425E-12 \quad C_7 = -0.17892321E-14$$

$$C_8 = 0.11112018E-16 \quad C_9 = -30994571E-19$$

For predict the temperature as a function of altitude (z), the following expression used [13].

$$T(z) = T_0 - R_a(z - z_0) \tag{4}$$

Where T_0 is the temperature at the lower altitude (Z_0) (10 m in the study which is represent the tower elevation of Nassiriyah meteorology station), R_a is the temperature laps rate (0.0065 $C^0 m^{-1}$).

From the following equation (Poisson equation) [13].

$$\frac{T_{(z)}}{T_0} = \left(\frac{P_{(z)}}{P_0}\right)^{\frac{R}{C_P}} \tag{5}$$

Where P_0 is the pressure at the lower altitude, then the pressure of dry air at any altitude (z) can be calculated by the following expression [13].

$$P(z) = P_0\left(\frac{T_{(z)}}{T_0}\right)^{C_P/R} \tag{6}$$

Where R the universal gas constant (8.31432), C_p is the constant - pressure specific heat of air, the amount of $\frac{C_P}{R} = 3.49$. The density of mixture of dry air molecules and water vapour molecules may be written in term of total pressure, temperature and actual water vapour pressure by the following expressions [12]:

$$\rho = \left(\frac{P}{R_d * T}\right)\left(1 - \frac{0.378 * e_a}{P}\right) \tag{7}$$

Where ρ is the moist density ((Kg/m^3), $e_{a=} RH^* e_s(T)$, $P = P_d + e_a$ is the total pressure , P_d is the pressure of dry air (partial pressure), R_d is the gas constant for dry air (*J/Kg.K*), T is the temperature in (*K*).

The density of dry air as a function of altitude (*ρ (z)*) calculated by the following equation [14].

$$\rho(z) = \rho_0 e^{-\left(\frac{0.297*Z}{3048}\right)} \tag{8}$$

Where (ρ_0) is the air density (1.255 Kg/m^3), (z) is the altitude. The wind speed calculated by the flowing equation [13,14].

$$v = v_0\left(\frac{Z}{Z_0}\right)^{\alpha} \tag{9}$$

Where (z_0), (z) are represents the lower altitude ((10*m*) in this study) and other under study altitudes respectively, v and v_0 are the wind speed at altitude (z) and (z_0) respectively, α is the ground surface friction coefficient. The net power of a practical wind turbine can be described by the following equation [15].

$$P_W = \frac{C_P \rho A v^3}{2} \tag{10}$$

Where A the swept area of turbine blades in m^2 is, v is the wind speed in *m/Sec*. C_p is the power coefficient, it's maximum theoretical value is a brooch to 0.59, but in practical designs the maximum value below 0.5 [13-16].

Calculations

The relative humidity, temperature and wind speed data of Nassiriyah city where measured at (10 m) altitude only (tower elevation of Nassiriyah meteorology station) for three years' time interval (2011-2013). These data where feed to Q-Basic program prepared in this study for simulation of air density, power, power density, pressure, temperature, relative humidity, saturation vapor pressure, actual vapor pressure and percentage losses of power because of relative humidity in moist air as a function of different altitudes (10-71 m) to estimate the effect of relative humidity on the extracted wind power at the feasible altitudes for electricity production in Nassiriyah city (32 meter for α = 0.4 and 44 meter for α = 0.3) [17]. Other data used in computations listed as: a blade radius (r) =10m, air density ρ = 1.225 Kg/m^3), power coefficient (C_p) = 0.5 [13-16], from reference [15] obtained the following data : ground surface friction coefficient (α) = 0.3, shape factor (k) = 2 m/sec, scalar factor (C) = 7 m/sec.

The computer subroutine programs execute the average daily computations for temperature, pressure, and the wind speed by using equations (4, 6, 9) respectively. The results has been utilized in equations (2, 3, 1), then it is possible to compute the density of moist and dry air by using equations (7, 8) respectively. The result of equation (7, 8) feed to compute the power by equation (10).

Results and Discussion

For computation checking; (Figure 1 (A, B, C)) shows the profile of relative humidity daily average for air according of measured and calculated data at (10 m) altitude for the time interval study (2011-2013) respectively. The figures appeared good consistence behaviour, the relative humidity daily average values decreases at the number of days (200 ± 20) which are characterized by high temperature degree. This behaviour is agree with mathematical relations and physical ideas. (Figure 2A-2C) confirms the inverse relation between the temperature and the relative humidity, and they shows the time variation of the daily average of each relative humidity and temperature at 35 m altitude for the years (2011-2013) respectively, the figures are in good identity with the published literature. While the (Figure 3A-3C) shows the relation between the annual average of the relative humidity and the temperature as a function of altitude, and they displayed the increasing of relative humidity with the increasing of altitude, on the other hand they displayed the decreasing of annual average of temperature with the increasing of altitude, that is related to the decreasing of the air pressure with increment of altitude.

(Figure 4A-4C) shows the comparison of annual average values of dry and moist air density as a function of altitude for the years (2011-2012). The figures clarified that the moist air density was less than the dry air density that is related to the moist air mass decrement comparing with the dry air, but each of their (moist and dry air density) increasing with altitude increment. For explain; there are two important factors (temperature and relative humidity) affecting on air density, therefore we have two cases of behaviour, the first one is resulting from the effect of temperature degree only (dry air density behaviour) thus it seems the density increasing with the increment of altitude due to decrease of temperature. The second one is resulting from the relative humidity and the temperature degree effects (moist air density behaviour) thus it seems the density increasing with the increment of altitude. The study explains that the temperature degree is the dominator factor from the relative humidity (the effect of relative humidity less than the temperature effect).

Figure 5 shows the percentage of loss occurring in the annual

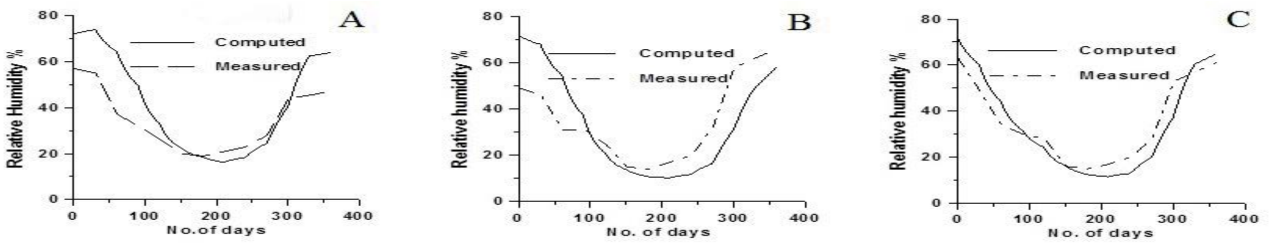

Figure 1: The profile of computed and the measured values of daily average of relative humidity at 10 m altitude for the years 2011-2013 respectively.

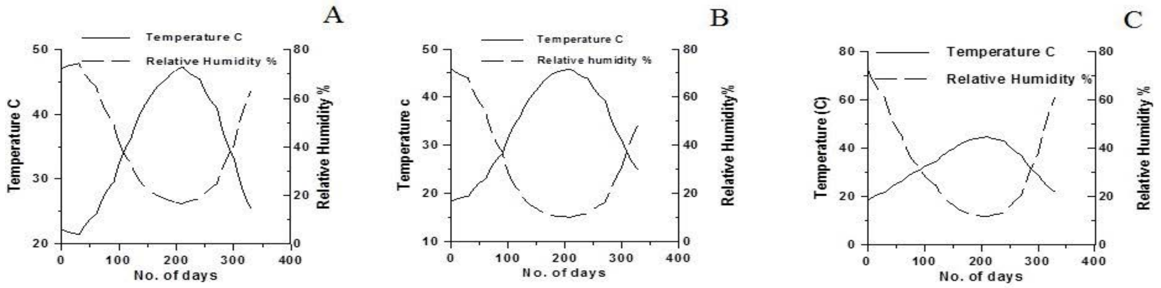

Figure 2: The behavior of the daily average for temperature and relative humidity at 35 m altitude for the years 2011-2013 respectively.

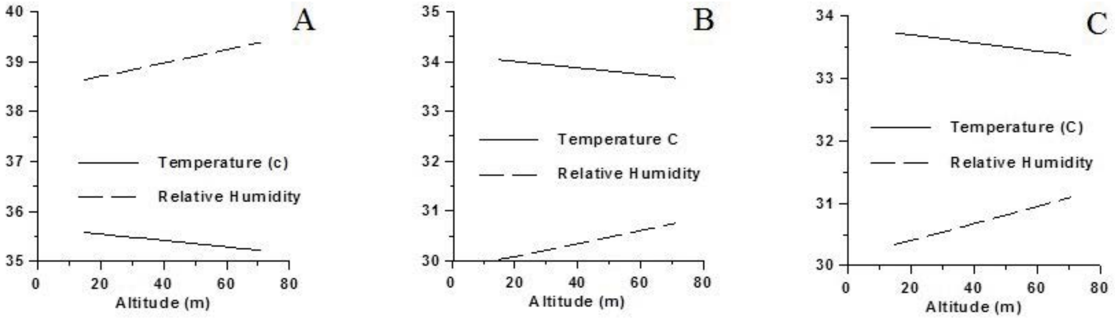

Figure 3: The profile of the annual average of temperature and relative humidity as a function of altitude for the years 2011-2013 respectively.

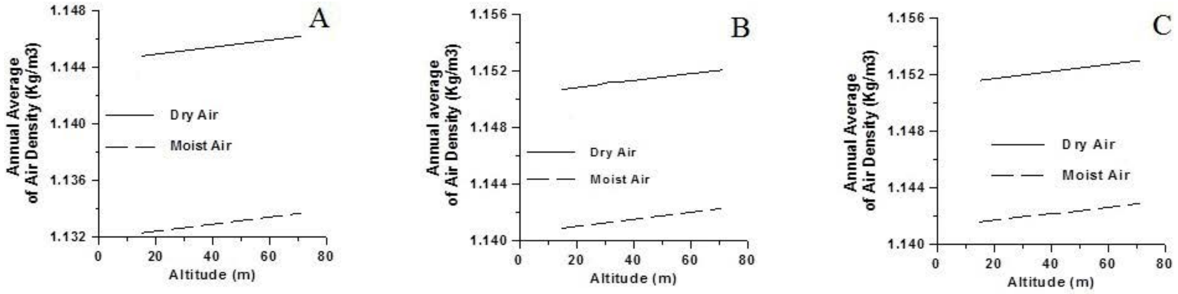

Figure 4: The profile of the annual average of the density for dry and moist air as a function of altitude for the years 2011-2013 respectively.

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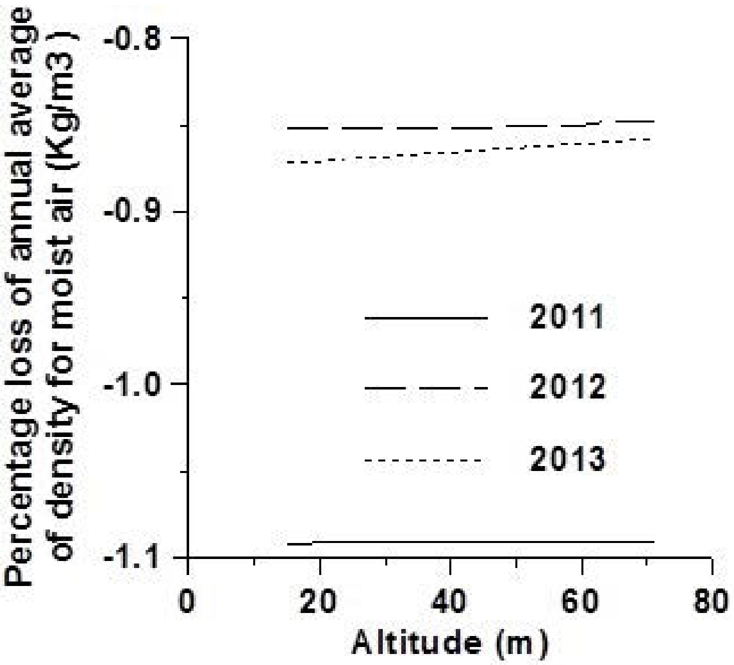

Figure 5: The percentage of loss of the annual average of density for moist air as a function of altitude for the years 2011-2013 respectively.

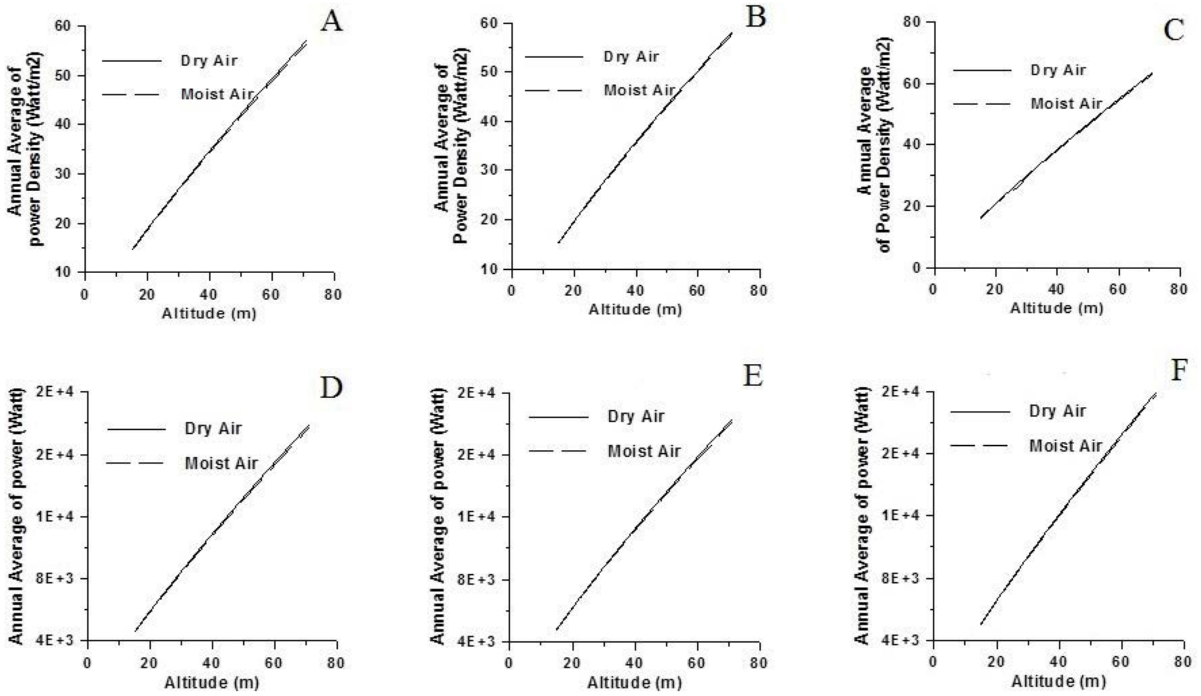

Figure 6: A, B, C. The profile of the annual average of power density for the dry and moist air as a function of altitude for the years 2011-2013 respectively. **D, E, F.** The profile of the annual average of power for the dry and moist air as a function of altitude for the years 2011-2013 respectively.

average of air density due to relative humidity as a function of altitude for the study time interval (2011-2013) respectively. It is appear that the max percentage of loss at the low altitude and vice versa (1.092%, 0.852%, 0.868% at (15 m) altitude for years (2011-2013) respectively (note: the negative sign refer to losses), while these values became 1.09%, 0.848%, and 0.858% at (71 m) altitude respectively. The study explains that related to mass decrement effect on air density due to humidity comparing with the volume decrement effect due to temperature decrease with the altitude increasing. In general, cane concludes that the effect of relative humidity on air density in Nassiriyah

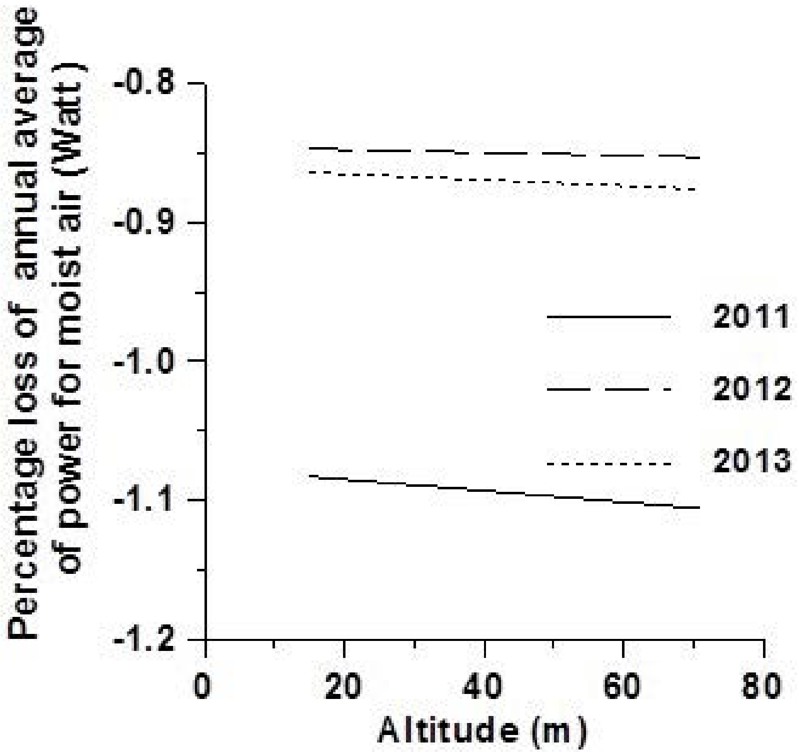

Figure 7: The percentage of loss of annual average of power for moist air as function of altitude.

city is a little.

(Figure 6A-6C) shows the variation of the annual average of power density as a function of altitude for the study interval time (2011-2013) respectively. It appears that the annual average of the power density of moist air less than dry air. (Figure 6D-6F) are enhancing (Figure 6A-6C) and shows the variation of the annual average of wind power for dry and moist air as a function of altitude for the years (2011-2013) respectively. It appears that the annual average of the power of moist air less than dry air and the variance increase with the altitude to be somewhat noticeable at high altitude, the computations results appear variance between the dry and the moist air at (15 m) altitude 51 watt, 41 watt, and 44 watt for the years (2011-2013) respectively, while this variance to be approach to 194 watt, 155 watt, and 174 watt for the same years respectively at 71 m altitude.

Figure 7 shows the percentage of loss occurring on the annual average of power due to relative humidity as a function of altitude for the study time interval (2011-2013) respectively. It is appear that the minimum percentage of loss at the low altitude and vice versa (1.083%, 0.847%, 0.864% at (15 m) altitude for years (2011-2013) respectively, (note: the negative sign refer to losses) while these values became 1.106%, 0.853%, and 0.876% at (71 m) altitude respectively. In general cane concludes that the effect of relative humidity on the annual average of wind power which is extracted in Nassiriyah city is a little, and the percentage of loss on the annual average of power for moist air (due to humidity effect) is increase with the increment of altitude comparing with the dry air.

Conclusion

The loss in the extracted power from wind as a renewable energy for electricity production due to relative humidity in Nassiriyah city - south of Iraq it is un effective and vary between (0.847% and 1.106%) at altitudes (15 m , 71 m) respectively.

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