Mathematical simulation of wind speed as a renewable energy in Nassiriya district : utilization for electricity product

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Abstract

The data of the wind speed in Nassiriya district (south of Iraq) has been measured in four years ago (2007-2010) at 10 m altitude and then, simulated mathematically to study and predict the important wind energy dynamic parameters as a necessary step before utilization the wind for electricity production job, as a knowledge no study will be focus on renewable sources (specifically wind energy) in Nassiriya district. The study shows that, the wind speed in Nassiriya district is suitable for electricity production if the tower of wind station at least (34m) altitude from the earth surface and (10 m) for rotor radius at least .

Key words: Physics energy, renewable energy, wind energy

الخلاصة :-

تم في هذا البحث محاكاة سرع الرياح في مدينة الناصرية للأعوام (2007-2010) من خلال برنامج حاسوبي أعد في هذا البحث وذلك لمعرفة مدى إمكانية توظيفها في إنتاج الطاقة الكهربائية وما هي الظروف او التصاميم المثلى لها كخطوة ضرورية قبل الدخول في تنفيذ هذه المشاريع حيث لم تتوفر أية دراسة سابقة في هذا المجال للمدينة المذكورة على حد علم الباحث. خلص البحث إلى إن سرعة الرياح في مدينة الناصرية تكون مشجعة لتوظيفها لإنتاج الطاقة الكهربائية عندما يكون ارتفاع برج المحطة 34 متر في الحد الأدنى ونصف قطر المروحة 10 متر في حده الأدنى.

1. Introduction

The energy sources can be split into three categories: fossil fuels, renewable sources, and nuclear sources. The combined effect of the depletion of fossil fuels and the gradually emerging consciousness about environmental degradation has given priority to the use of conventional and renewable energy sources such as wind, hydro, geothermal, and solar sources.

The rapid development in wind energy technology has made it an alternative to conventional energy systems in recent years and wind power as a potential energy has grown at an impressive rate. The potential benefits of wind power as a clean (does not causes acid rain or atmospheric heating, no CO_2 emission, no harm to nature and human health, no radioactive effect), renewable, and economic. This reduction in wind energy cost is the result of improved aerodynamic designs, advanced materials, improved power electronics, advanced control strategies and rigorous component testing [1-6].Wind turbines have continued to evolve over the past 20 years and the overall cost of energy required to produce electricity from wind is now competitive with traditional fossil fuel energy sources [3,4].

Advocates for wind energy maintain that it could provide 12 percent of all electric power generated in the world by the year 2020 [6]. For environmentalists concerned about pollution, policy makers concerned about reliance on fossil fuels, and investors hoping to profit from a new source of energy, the advancement of wind power holds wonderful promises.

However, for power grid operators, the advancement of wind energy holds many challenges. Wind power is unsteady, unpredictable, and harnessed in relatively small quantities at points spread over a large area. If it is not properly controlled. Wind farms cannot be tied directly to the power grid without devices to help regulate and control their output. However, the most technologically advantageous wind energy conversion system features a superb power electronic interface to the external power grid to which it is connected. This system, which is referred to as direct drive synchronous, features a synchronous generator whose AC output is immediately rectified to DC, and is then inverted back to an AC voltage that is compatible with the grid into which it is being fed. This systemic is highly advantageous because the inverter can control both the reactive power content and the frequency of the electricity being put onto the grid [7].

In this paper as a my knowledge, it is the first mathematical study will be focus on renewable sources (specifically wind energy) in Nassiriya district which is located in south of Iraq, 4.5 meter above sea level, 31(east) with 46 (north) intersection lines [7].

2. Theory

The kinetic energy $(K.E.)$ in air mass (m) moving with speed (v) is given by

$$K.E. = \tfrac{1}{2} m v^2 \,(joule) \tag{1}$$

The mechanical power of air mass flow rate per second moving with speed (v) is given by

$$P = \tfrac{1}{2}(\rho A v).v^2 = \tfrac{1}{2}\rho A v^3 (watt) \qquad (2)$$

Where (ρ) is the air density (Kg/m^3), $(A = \pi D^2/4)$ is the area swept by the rotor blades (m^2), (D) is the rotor diameter. The amount (Av) is the volumetric flow rate, then the amount $(\rho A v)$ in Eq. (2) represents the mass flow rate of the air in kilograms per second. The specific power density is the power in Watt per square meter of area swept by the rotating blades can be given by the following expression:

$$S.P. = \tfrac{1}{2}\rho V^3 \qquad (3)$$

The actual power extracted by the rotor blades (P_o) is the difference between the upstream and the downstream wind power, then by using Eq.(2) :

$$P_o = \tfrac{1}{2}(\rho A)[v^3 - v_o^3] \qquad (4)$$

Where (v, v_0) are the upstream wind speed (at the entrance of the rotor blades) and the downstream wind speed (at the exit of the rotor blades) respectively. The air speed is discontinuous from (v) to (v_o) at the plane of the rotor blades, it is suitable to use the average speed [8] and rearrange Eq. (4) as a follows:

$$P_o = \tfrac{1}{2}(\rho A)[\tfrac{1}{2}(v^3 - v_o^3)] = \tfrac{1}{2}(\rho A)[\tfrac{1}{2}(v + v_o)(v^2 - v_o{}^2)]$$

$$P_o = \tfrac{1}{2}(\rho A v^3)[\tfrac{1}{2}(1 + \tfrac{v_o}{v})(1 - (\tfrac{v_o}{v})^2]$$

$$P_o = \tfrac{1}{2}\rho A v^3 C_p \qquad (5)$$

Where $C_p = \tfrac{1}{2}(1 + \tfrac{v_o}{v})(1 - (\tfrac{v_o}{v})^2)$ is called the power coefficient of the rotor or the rotor efficiency, the value of C_p depends on the ratio of the downstream to the upstream wind speed and the theoretical maximum value of C_p is 0.59, but in practical designs the maximum value below 0.5 [8,9].

The air density at sea level, one atmospheric pressure (14.7psi) and $60^{o}F$ is $(\rho_o = 1.225)$ Kg/m^3 and is corrected for the sit specific temperature and pressure. The temperature and pressure both in turn vary with the altitude. Their combined effect on the air density is given by [8]

$$\rho = \rho_o e^{-\left(\frac{0.297 H_m}{3048}\right)} \tag{6}$$

Where H_m is the site elevation in meters.

2.1 Wind speed distribution (Weibull probability distribution)

There are several density functions can be used to describe the wind speed frequency curve. The most two common are the Weibull and Rayleigh function [9]. The Weibull function is a two parameter distribution while the Rayleigh function has only one parameter. This makes the Weibull function somewhat more versatile and the Rayleigh function somewhat simpler to use, Weibull probability distribution (h) of wind speed being (v) during any time interval is given by [8,9]

$$h(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^k} \quad \text{for } 0\langle v \text{ and } 0\langle k \tag{7}$$

Where $h =$ [(number of hours in which the wind is between v and $(v + \Delta v)$)/ Δv], (k) is the shape parameter, and (c) is a scale parameter mile/hour(mph=0.446 m/sec) ranging from 10 to 20 mph (about 5 to 10 m/sec) [8]. The characteristics of the Weibull probability distribution function Summarizing

1- If k =1 makes it the exponential distribution,

2- If k =2 makes it the Rayleigh distribution,

3- If k >3 makes it approach a normal bell-shape distribution,

The wind shear at ground surface causes the wind speed increase with height in accordance with the following expression [8, 9]

$$v_1\left(\frac{h_2}{h_1}\right)^{\alpha} = v_2 \tag{8}$$

Where v_1 is the wind speed measured at the reference height h_1, v_2 is the wind speed estimated at height h_2, and (α) is the ground surface friction coefficient determined empirically [9], The typical values for terrain classes are given in Table (1) [8].

Table (1) : Friction coefficient of various terrain

Terrain type	Friction coefficient (α)
Lake, ocean and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

2.2 Mode Speed, Mean Speed, and Root Mean Cube Speed

Mode speed is defined as the speed corresponding to the hump in the distribution function . Mean wind speed over the period is defined as the total area under the $h-v$ curve integrated from v=0.0 to ∞, divided by the total number of hours in the period (8760 if the period is one year). The annual mean wind speed is therefore the weighted average speed and is as follows:

$$v_{mean} = \frac{1}{8760}\int_0^{\infty} hv\,dv \tag{9}$$

The speed every hour averaged over the day, which in turn was averaged over the month and over the year, the averaging was done as follows:

$$v_{avg} = \frac{1}{n}\sum_{i=1}^{n} v_i \qquad (10)$$

Where n is the number of observations in the averaging period, v_i is the wind speed at the ith observation time.

The wind power is proportional to the speed cube, and collected over the year (equivalent the integral of (hv^3dv), therefore, define the root mean cube (rmc) speed in the manner similar to the root mean square (rms) value

$$v_{rmc} = \sqrt[3]{\frac{1}{8760}\int_{0.0}^{\infty} hv^3 dv}$$

$$v_{rmc} = \sqrt[3]{\frac{1}{n}\sum_{i=1}^{n} v_i^3} \qquad (11)$$

Eq. (11) does not take into account the variation in the air mass density which is a parameter in the wind power density. Therefore a better method of collecting the wind power data is to digitize the yearly average power density (watt/m^2) as follows:

$$P_{rmc} = \frac{1}{2n}\sum_{i=1}^{n} \rho_i v_i^3 \qquad (12)$$

3. Calculations, Results, and Discussion

The data of the wind speed in Nassiriya district has been measured for four years ago (2007-2010) at 10 m altitude (tower height Nassiriya station of meteorology), this data has been feed into a computer program which is buildup in this study to predict the wind energy dynamic parameters by calculations. The input data was used tabulated in the following table:

Parameter	Value
Blade radius (r)	5 m
Air density (ρ_o) (Kg/m^3)	1.225 at sea level (14.7Psi and 60^{0}F)
Power coefficient (C_p) Kg/m^3	0.5
Friction coefficient (α)	0.4
Rated rotation rate(rpm)	90
Shape factor (k)	2
Scale factor (c)	7 m/sec

The air density sweeping the blades was corrected with the altitude in computations. The mean wind speed, mean power density, annual average power density ,and the wind distribution function are studied in this study as a function of height for the time interval (2007-2010).

Fig.(1) shows the variation of the annual mean of wind speed as a function of height, the study shows the increase of the annual mean speed with the increasing of height as a linear relation approximately at the low heights and exhibit gradually increment at high heights. The aim of this part of the study to determine the height (altitude) which is satisfy the minimum value of the annual mean speed is suitable for electricity production, the literatures consider this value approach to (4.5-5) m/sec [10]. Then from fig. (1); the estimated value of the annual mean speed approach to 5m/sec approximately at (30 m) height through the time interval (2007-2009) (4.9, 4.91, and 5.09 m/sec respectively) but from 2010 this value is readil satisfied at the height less than 30 m . Fig. (2) represent the variation of the annual mean power (watt) with the height (m), the fig. shows the increase of the annual mean power while the height increasing . At the height equal to 30 m; the annual mean power approach to 2975,3047,3047and 6487Watt respectively for each year of time interval (2007-2009).The aim of this part is to study and determine how much the annual mean power extracted from the wind at height 30 m (minimum annual mean wind speed 5m/sec). Fig. (3) shows the increase of annual mean power density (Watt/Cm^2) while the height increasing, at the height equal to 30 m; the values of annual mean power density are approach to 37.9, 38.82,42.83 and 82.42 (watt/Cm^2) respectively for each year of time interval (2007-2009). Fig. (4) shows the Weibuall distribution of the percent of day/year at 30m and 34 m height for (2007), it is clear from distribution that much number of days to be characterized by speed more than 5 m/sec and the range of the percent of day/year which possess speed more than 5 m/sec extended from 11.7 to 12.25 at 30 m height(see fig.(4-a)) and 10.2 to 12.25 at 34 m height(see fig.(4-b)). Also from Figs.(5,6, and 7) for years (2008, 2009, and 2010) respectively show good percent of day/year which possess speed more than (5 m/sec). Then the number of days to be characterized by speed more than (5 m/sec) for both heights (30m,34m) are very much and suitable or encouraging to electricity production. Fig (8) shows the increasing of annual mean power versus rotor radius for two different heights (30m&34m) for 2010 only, these heights are chosen since they satisfied the wind speed 5m/Sec. A similar results has been found from calculations for 2007,2008,and 2009 are tabulated in table (2).

4. Conclusion

The wind speed in Nassiriya district is suitable or encouraging to electricity production at least 34m altitude from the earth surface and 10 m for rotor radius .

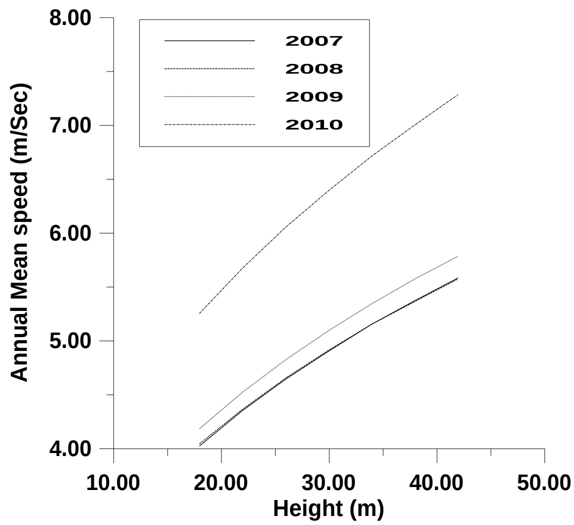


Fig (1): The variation of annual mean speed as a function of height

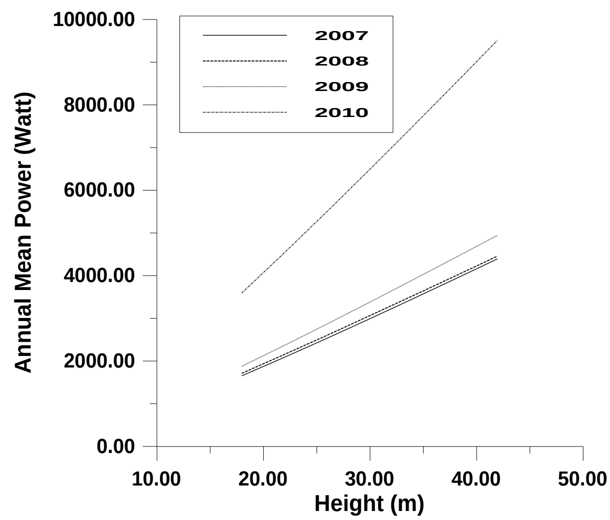


Fig (2): The variation of annual mean power as a function of height

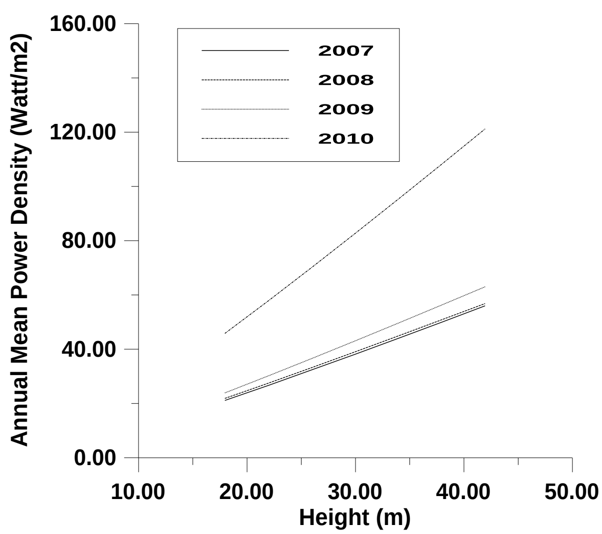
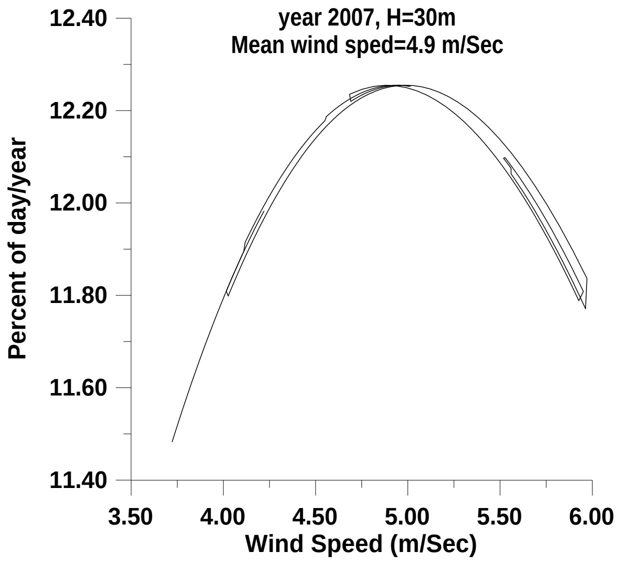
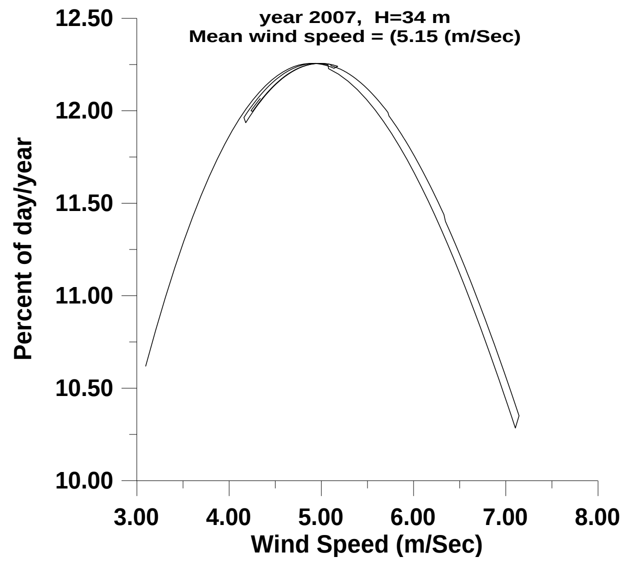


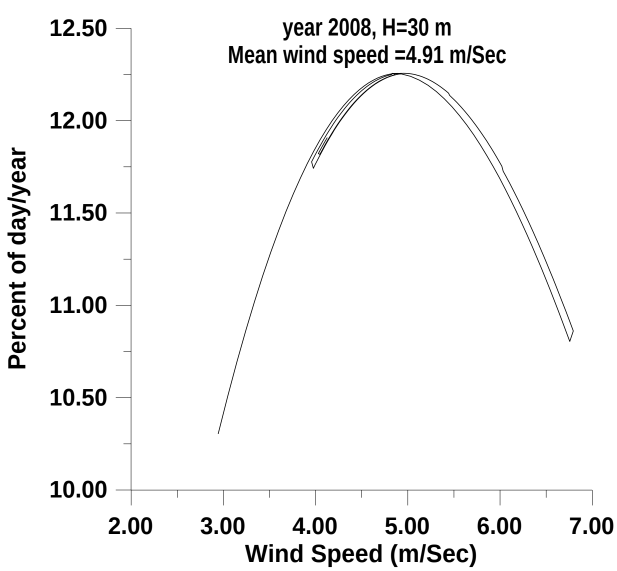
Fig (3): The variation of annual mean power density as a function of height



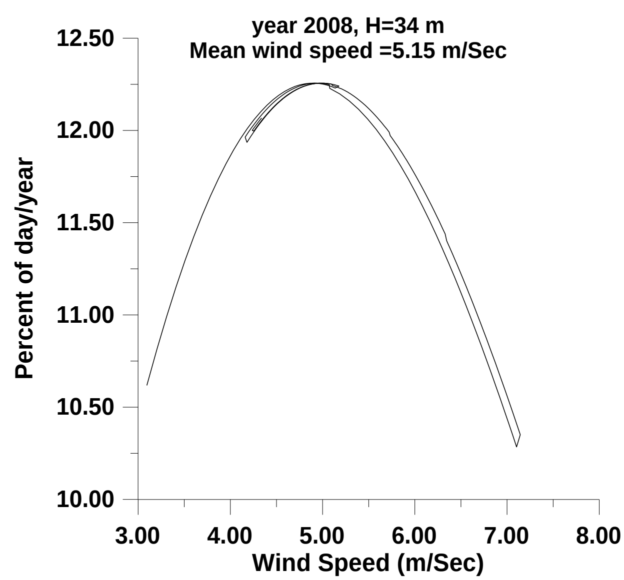
Fig(4-a): Weibuall distribution of day/year at 30 m height,(2007)



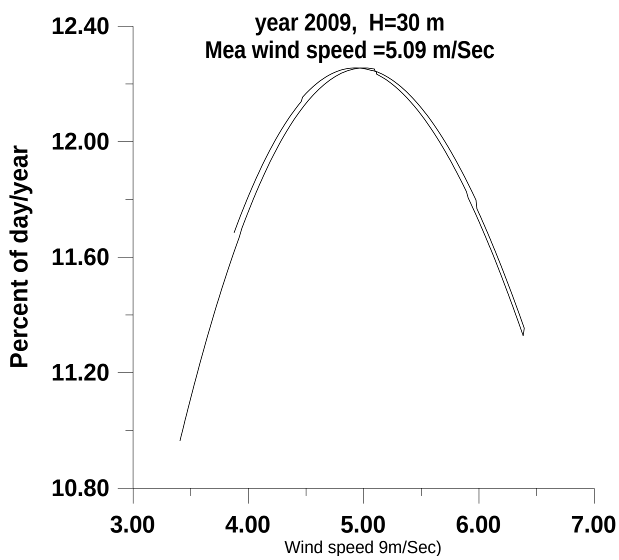
Fig(4-b): Weibuall distribution of day/year at 34 m height ,(2007)



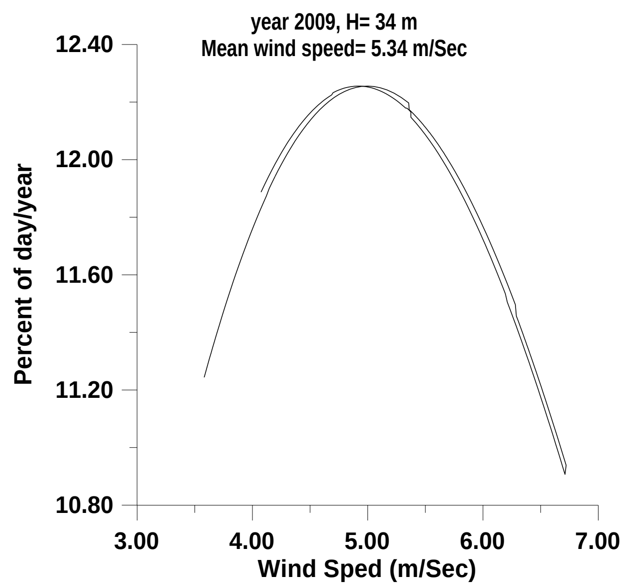
Fig(5-a): Weibuall *d*istribution of day/year at 30 m height,(2008)



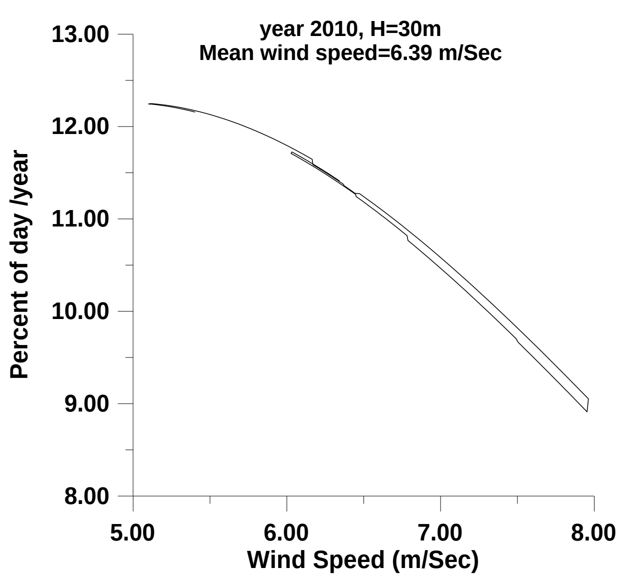
Fig(5-b): Weibuall distribution of day/year at 34 m height,(2008)



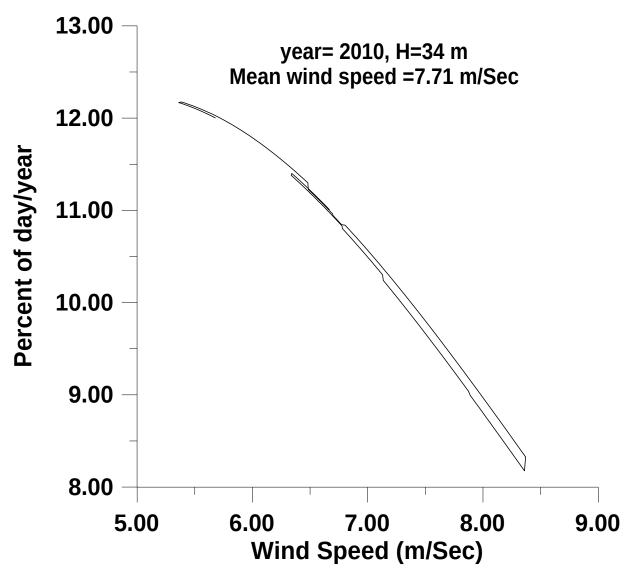
Fig(6-a): Weibuall distribution of day/year at 30 m height,(2009)



Fig(6-b): Weibuall distribution of day/year at 34 m height,(2009)



Fig(7-a): Weibuall distribution of day/year at 30 m height,(2010)



Fig(7-b): Weibuall distribution of day/year at 34m height,(2010)

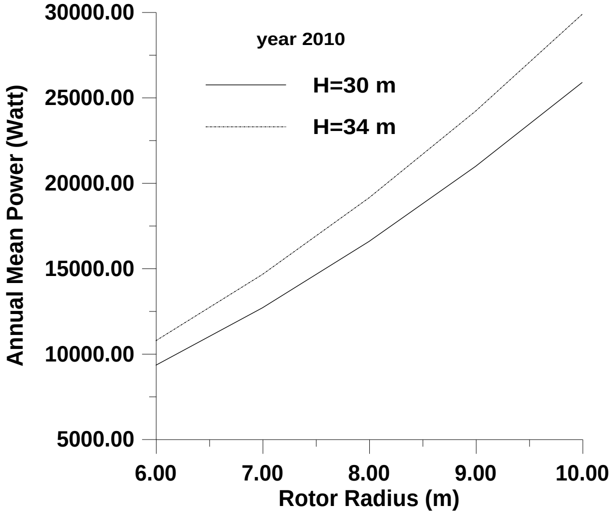


Fig (8): The variation of annual mean power versus rotor radius for two different heights, (2010)

Table (2): Annual mean wind power as a function of rotor radius for four years interval (2007-2010) ,with H=34 m

Rotor Radius (m)	Power (Watt)			
	2007	2008	2009	2010
5	3437	3509	3881	7468
6	4950	5054	5588	10754
7	6737	6879	7606	14637
8	8800	8984	9935	19118
9	11138	11371	12574	24197
10	13750	14038	15524	29873

References

[1] - "Transmission and wind energy :Capturing the prevailing wind for the benefit of customers", National Grid , (2006).

[2]- Erkan Erdogdu, "On the wind energy in Turkey", Renewable and sustainable energy reviews ,(13),(1361-1371), (2009).

[3] Harrison, R., Hau, E., Snel, H.," Large Wind Turbines: Design and Economics", Wiley Chichester,(2000).

[4] Puneet Malhotra," New Method for Dual-Axis Fatigue Testing of Large Wind Turbine", University of Massachusetts, Amherst,September 2010.

[5] P. Fairley, "Steady As She Blows" IEEE Spectrum, August 2003,pp35-39.

[6] Gerald Robert Callison," An evaluation of the cascaded H-bridge multilevel inverter topology for direct –drive synchronous wind farm applications", May 2006.

[7]- Meteorological station of Nassiriya city, Thi- Qar , Iraq**.**

[8] Mukund R.Patel," Wind and Solar Power System", U.S. Merchent Marine Academy , New York, CRC Press LLC,1999.

[9] Gary L. Johnson ","Wind Energy Systems", Electronic Edition, Manhattan, 2006

[10] Energy from the wind ", practical action, Schumacher Center for technology & Development Bourton Hall.

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