WIND TURBINE PERFORMANCE ANALYSIS

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Abstract: This research includes formation a mathematical model after taking balances of energy, (wind kinetic energy with the resulting energy from wind turbine performance). According to that, the efficiency of wind turbine were calculated depending on the velocity of the wind, taking into account the impact of climates condition for example, temperature humidity and velocity on turbines work. . In addition the results were compared with the results obtained from the operation of the laboratory turbine in the department and it turned out higher congruence results, which confirms the success of the model.

Key words: Wind turbine, Mathematical model, Kinetic energy.

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Nomenclature

Symbols	Description	Units
A	**Rotor Swept Area**	m^2
Cp	**Performance coefficient**	-----
Ng	**Gearing efficiency**	-----
Nb	**Bearing efficiency**	-----
ρ	**Air density**	Kg/m^3
d	**Rotor diameter**	m
R	**Resistance**	ohm
N	**Number of blade**	-----
M	**Mass of air**	$m^{3/}kg$
$\dot{v}$	**Volume rate**	Kg/sec
V	**Wind speed**	m/s
V	**Voltage**	v
λ	**Tip speed ratio**	-----

Table (1)

1- Introduction

Renewable energy is not like other classical energy, which is, it doesn't come to end because, it comes from lasting sources, for example wind, sun, waves, oceans. Winds is rounds us everywhere, and this happened for many reasons, one of them the differences in temperature between regions on the surface of the earth, moreover the diversity in climates conditions between regions and the contrariety in temperatures degree between sea and land. Wind energy considered to be a renewable energy. To better understand how wind power works and what makes wind turbines rotate, take a look at how an aircraft gets off the ground. The aerofoil splits the wind into two portions as the wind hits it; one goes over the top and the other under the bottom. Airflow on the top moves as high velocity and has a low pressure while airflow under the aerofoil is moving at slower velocity and has high pressure. Wind power is actually created from the movement of high pressure to low pressure and an aerofoil created a pressure difference between the top and the bottom parts. Then a low pressure air on top of the aerofoil tries to suck the aerofoil and the air underneath it pushes it upwards. The air under the aerofoil is actually trying to push the aerofoil upwards to reach the low pressure. The result of this action is what we call the "lift." In airplanes, the lift happens because the large turbine engines force the wings through the air at a high velocity. On the other hand, in a wind turbine, we would rely solely for the wind to hit the aerofoil as it is stationary [1]. Wind turbine blades are shaped similar to the shape of the wings of a plane, only with slight differences. So what happens when wind hits the blade of a turbine is the same lift force that affects a wing on a plane. But because the blades are attached to a stationary machine, instead of a lift force to cause the rotor to lift into the sky, the blade then spins round and round. This is what creates rotational energy which then will be converted to electricity by the generator. The blades of the turbine are usually pitched at a certain angle to get the maximum amount of 'lift' from the wind [2].

The actual first accounts of using wind power were by the first boats that had incorporated sails to move them. This is the first and original concept of wind power. The first sailors to use wind to power their boats did not have an understanding of the physics that made the wind power their sails. In 500 A.D.[3]. Windmills was used by Persia for watering crops by pumping out water from streams, wells or lakes. It was not until 1888 that wind power was first used as a source of electricity. This test model was created in Cleveland Ohio but did not produce very strong electrical currents even though it was in use for twenty years. The first viable windmill to generate electricity was in Europe in 1891. These wind powered generators produced electricity on a grander scale than those that were in use up to that time. They used time tested blades that would spin faster and therefore would generate more electricity. By World War I, these units were employed all over Denmark and it was not until the use of fossil fuels to generate electricity took over that the windmill as an electrical source died out [4].

Figure (1) below, shows the cost of electrical energy by using natural and propane gas in the last decades in the United state of America [5].

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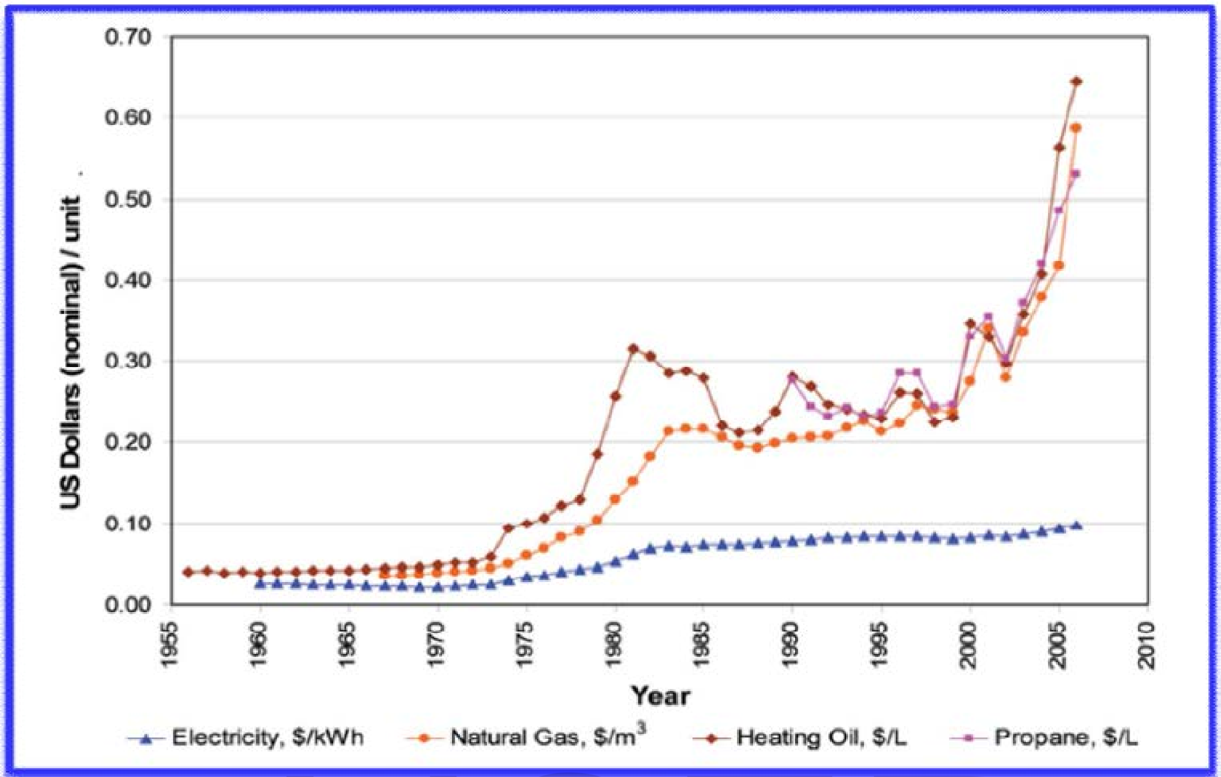

Figure (1) below, shows the cost of electrical energy by using natural and propane gas in the last decades in the United state of America

Figure (3) indicates, the increasing of electric energy consuming in Kirkuk city for 2011-2013, it shows that utilizing electric energy has been doubled from 255Mwatt for 2003 to 480Mwatt for 2011 (Kirkuk Electric disturbing office data)

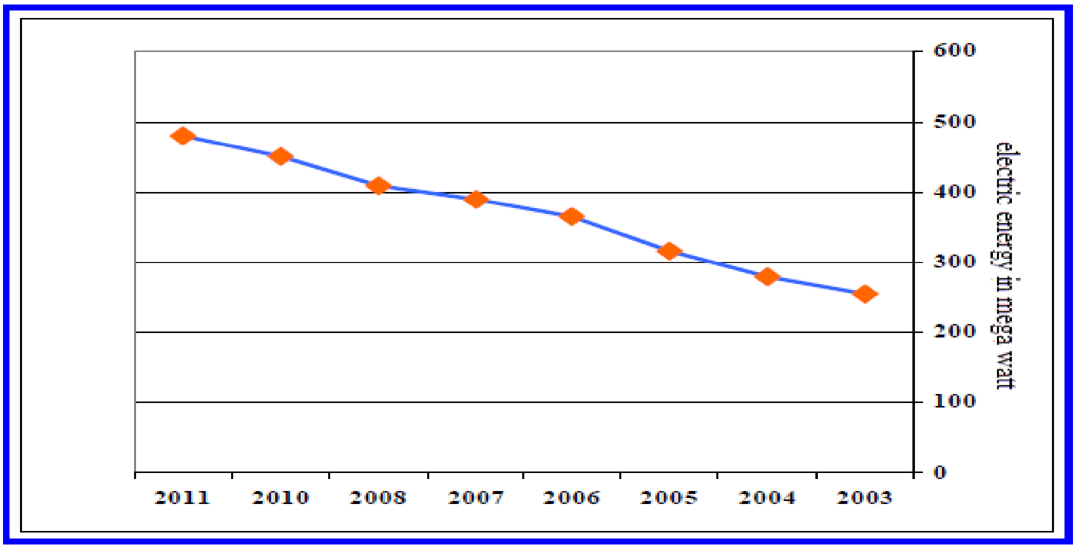

figure (3) shows consuming of electric energy in Kirkuk city for 2011-2013

2- Modeling Wind turbines work

In the figure (4) below the available wind power which is able to rotate the blades of the wind turbine, and the main factors which rise to calculate the rate of tip speed of blade (TRS), which is the key factor in designing windy blade [6].

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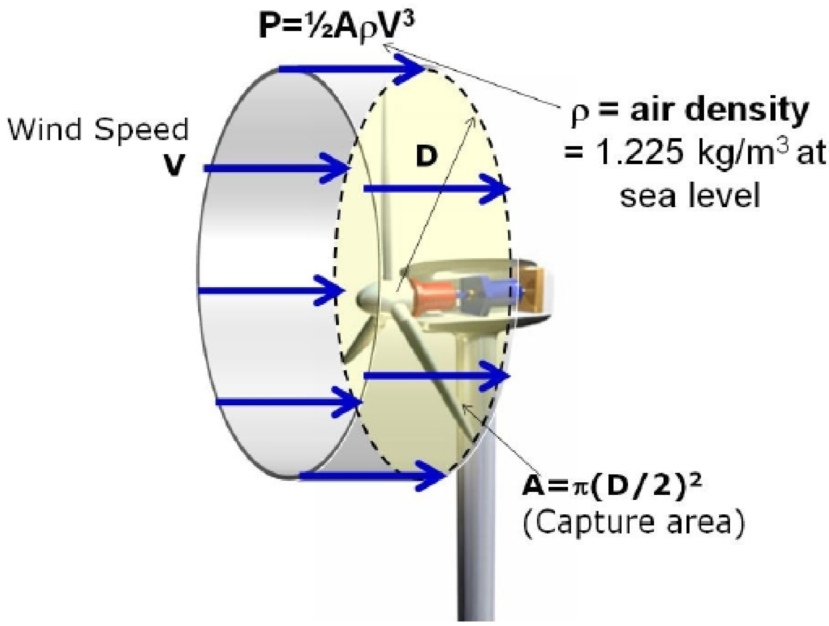

Figure (3) shows the factors effects on calculating TSR

$$TSR(\lambda) = \frac{\textit{Tip Speed of Blade}}{\textit{Wind Speed}}$$

If the rotor of the blade rotates slow velocity, then most of the wind will pass straightly through the gaps between the blades, and there will be no power to give. But if the rotor rotates with extremely high velocity the blades will acts as a dam against the wind, and it will rotate unsteady rotation[7]. We should aware of the time needed to for the blades to complete one rotation, after that we can calculate the tip speed of blade. Then by using the following equation we can determine the TSR:

$$\mathbf{V} = \frac{2\pi r}{\mathbf{T(time)}}$$

Where:

V- Velocity of tip (m/s)

$2\pi r$- Area swept by the blades to complete one rotation (m^2)

T – Time needed to complete one rotation (s)

Velocity of wind can be determined either by Kestrel meter, or any other measurement device used for measuring wind velocity, or the velocity in another practical method. If TSR is larger than one, that means we need to increase the high of the tower to make the turbine wheel rotate fast, and if the TSR is less than one, it means, there is a huge resistance against the air making an obstacle in the way of turbines wheel rotation[8].

3. How can we know the ideal ratio of the tips speed?

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If we want to obtain an ideal ratio of tips speed in order to gain high power on the outlet, the optimum Tip Speed Ratio for maximum power output, this formula has been empirically proven[9].

$$\boldsymbol{\lambda(\text{Max power})\frac{4\pi}{n}}$$

Where:

λ- Tip speed ration

n- Number of blades [10]

Number of blades	Tip speed ratio
2	About 6
3	About 4-5
4	About 3
6	About 2

4. Application of conservation of mass (continuity equation)

Applying conservation of mass to this control volume, the mass flow rate (the mass of fluid flowing per unit time) is given by:

$$\dot{m} = \rho A_1 v_1 = \rho S v = \rho A_2 v_2$$

where v_1 is the speed in the front of the rotor and v_2 is the speed downstream of the rotor, and v is the speed at the fluid power device [11]. ρ is the fluid density, and the area of the turbine is given by S. The force exerted on the wind by the rotor may be written as

$$\begin{aligned} F &= ma \\ &= m\frac{dv}{dt} \\ &= \dot{m}\,\Delta v \\ &= \rho S v (v_1 - v_2) \end{aligned}$$

Power and work

The work done by the force may be written incrementally as

$$dE = F \cdot dx$$

and the power (rate of work done) of the wind is

$$P = \frac{dE}{dt} = F \cdot \frac{dx}{dt} = F \cdot v$$

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Now substituting the force F computed above into the power equation will yield the power extracted from the wind:

$$P = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2)$$

However, power can be computed another way, by using the kinetic energy. Applying the conservation of energy equation to the control volume yields

$$P = \frac{\Delta E}{\Delta t}$$
$$= \frac{1}{2} \cdot \dot{m} \cdot (v_1^2 - v_2^2)$$

Looking back at the continuity equation, a substitution for the mass flow rate yields the following

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2)$$

Both of these expressions for power are completely valid, one was derived by examining the incremental work done and the other by the conservation of energy. Equating these two expressions yields

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2) = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2)$$

Examining the two equated expressions yields an interesting result, mainly

$$\frac{1}{2} \cdot (v_1^2 - v_2^2) = \frac{1}{2} \cdot (v_1 - v_2) \cdot (v_1 + v_2) = v \cdot (v_1 - v_2)$$

or

$$v = \frac{1}{2} \cdot (v_1 + v_2)$$

Therefore, the wind velocity at the rotor may be taken as the average of the upstream and downstream velocities. (This is arguably the most counter-intuitive stage of the derivation of Betz' law.)

Betz' law and coefficient of performance

Returning to the previous expression for power based on kinetic energy:

$$\dot{E} = \frac{1}{2} \cdot \dot{m} \cdot \left(v_1^2 - v_2^2\right)$$
$$= \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot \left(v_1^2 - v_2^2\right)$$
$$= \frac{1}{4} \cdot \rho \cdot S \cdot (v_1 + v_2) \cdot \left(v_1^2 - v_2^2\right)$$
$$= \frac{1}{4} \cdot \rho \cdot S \cdot v_1^3 \cdot \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right).$$

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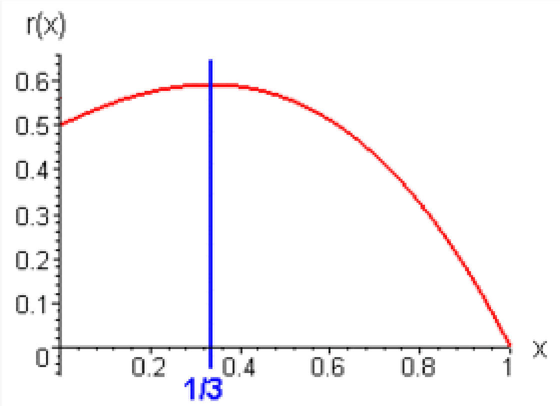

The horizontal axis reflects the ratio v_2/v_1, the vertical axis is the "power coefficient C_p.

By differentiating $\dot{E}$ with respect to v_2/v_1 for a given fluid speed v_1 and a given area S one finds the *maximum* or *minimum* value for $\dot{E}$. The result is that $\dot{E}$ reaches maximum value when $\frac{v2}{v1} = \frac{1}{3}$.

Substituting this value results in:

$$P_{\text{max}} = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3.$$

The power obtainable from a cylinder of fluid with cross sectional area S and velocity v_1 is:

$$P = C_{\text{p}} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3.$$

The reference power for the Betz efficiency calculation is the power in a moving fluid in a cylinder with cross sectional area S and velocity v_1:

$$P_{\text{wind}} = \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3. \quad [12]$$

The "power coefficient C_p (= P/P_{wind}) has a maximum value of: $C_{p.max}$ = 16/27 = 0.593 (or 59.3%; however, coefficients of performance are usually expressed as a decimal, not a percentage).

5. Practical Part

The figures below (1-5) and (2-5) respectively shows, Wind Energy Laboratorial device

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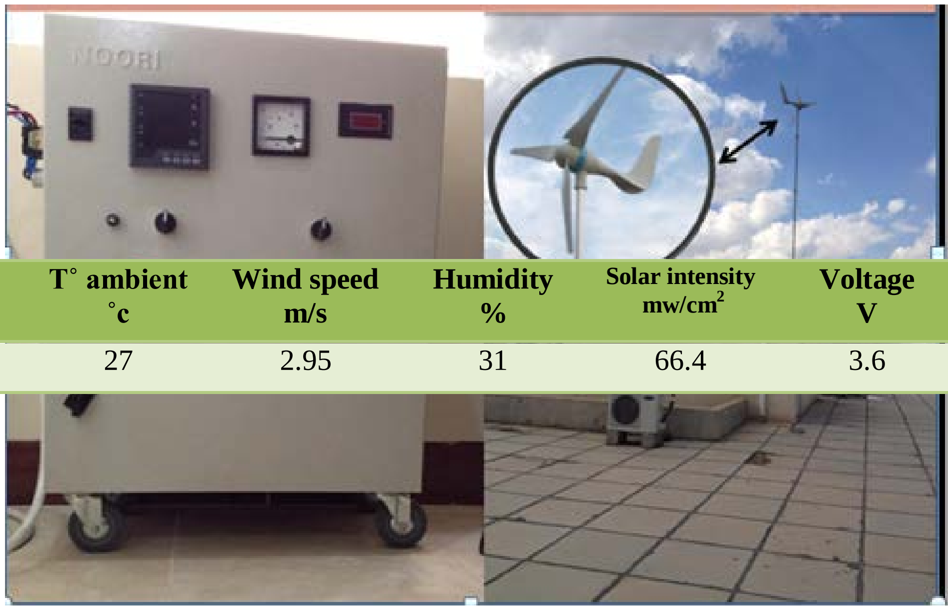

Time	T° ambient °c	Wind speed m/s	Humidity %	Solar intensity mw/cm^2	Voltage V	Efficiency %
09:00	27	2.95	31	66.4	3.6	17.35

figure(1-5) Laboratory wheel turbine

figure (2-5) Laboratory measuring device and control panal

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Time	T° ambient ˚c	Wind speed m/s	Humidity %	Solar intensity mw/cm^2	Voltage V	Efficiency %
09:30	25	3.55	28	81.7	4.120	13.4
10:00	24.4	3.68	31	83.7	4.123	12
10:30	25.7	3.5	30	87.0	4.25	14.8
11:30	25.7	5.75	30	100	7	9
12:00	27.6	3.33	28	101.1	4.2	16.8
12:30	26	12.2	27	102.5	20.12	7.32
01:00	26	12.5	25	199.2	21	7.9
01:30	26.6	11.8	25	98	19.33	8
02:00	26	10.3	25	97.5	18	10.19

6. Expected Results

The table (2) below shows the reading for **04/05/2015**

Table(2)

Table (3) shows the reading for date **04/06/2015**

Table (3)

Time	T° ambient ˚c	Wind speed m/s	Humidity %	Solar intensity mw/cm^2	Voltage V	Efficiency %
09:00	21.9	3		62.8	2.78	10.1
09:30	22	3.5	34	79.0	3.78	11.7
10:00	23.6	3.9	32	86.8	4.02	9.6
10:30	23.6	4.2	30	94.1	5.4	13.7
11:00	26.7	5	28	102.5	6.3	11.2
11:30	26.9	6.5	28	96.0	7.3	6.48
12:00	25.9	4.2	28	102.9	4.8	11
12:30	27.7	3.52	25	101.3	3.7	11.1
01:00	26.2	3.95	25	94.5	4.4	11.1
01:30	26.1	4.02	25	91.6	4.1	9.1
02:00	28.2	4.8	20	93.0	5.2	8.6

Table (4) shows the reading for date **04/07/2015**

09:00	26.7	6.22	32	61.7	9.55	13
09:30	25	4.26	30	67.0	5.9	15
10:00	25.9	3.5	28	79.0	4.7	18.2
10:30	29	3.03	20	94.3	4.5	16
11:00	30.4	4.75	20	98.6	6.5	13.5
11:30	29.9	5.65	20	64.9	7.5	10.7
12:00	30.7	3.3	20	76.5	4.5	19.3
12:30	30.9	4.55	20	99.4	5.3	10.5
01:00	31.6	4.73	20	63.8	5.61	10.51
01:30	31.4	3.55	20	40.8	4.96	19.43
02:00	35	5.64	20	38.0	6.76	9

Table (4)

7. Experimental Work

$$\mathbf{M = \quad A\ V}\ \text{--}\mathbf{1}$$

$$\mathbf{KE = \frac{1}{2}\ M\ V^2}\ \text{-----------------------------------}\mathbf{2}$$

Adding (1) one (2) we got

$$\mathbf{KE = \frac{1}{2}\,.(\rho\ .\ A\ .\ V\ )\ V^2}$$

$$\mathbf{KE = \frac{1}{2}.\ \rho\ .\ A\ .\ V^3}$$

Power out can be calculated from the formula of Electric Power Formulas which is:

$$\mathbf{P_{out} = \frac{V^2}{R}}$$

Where :

V^2 - voltage (volts, V)

R- Resistance (ohms, Ω)

The theoretically available power in the wind can be expressed as:

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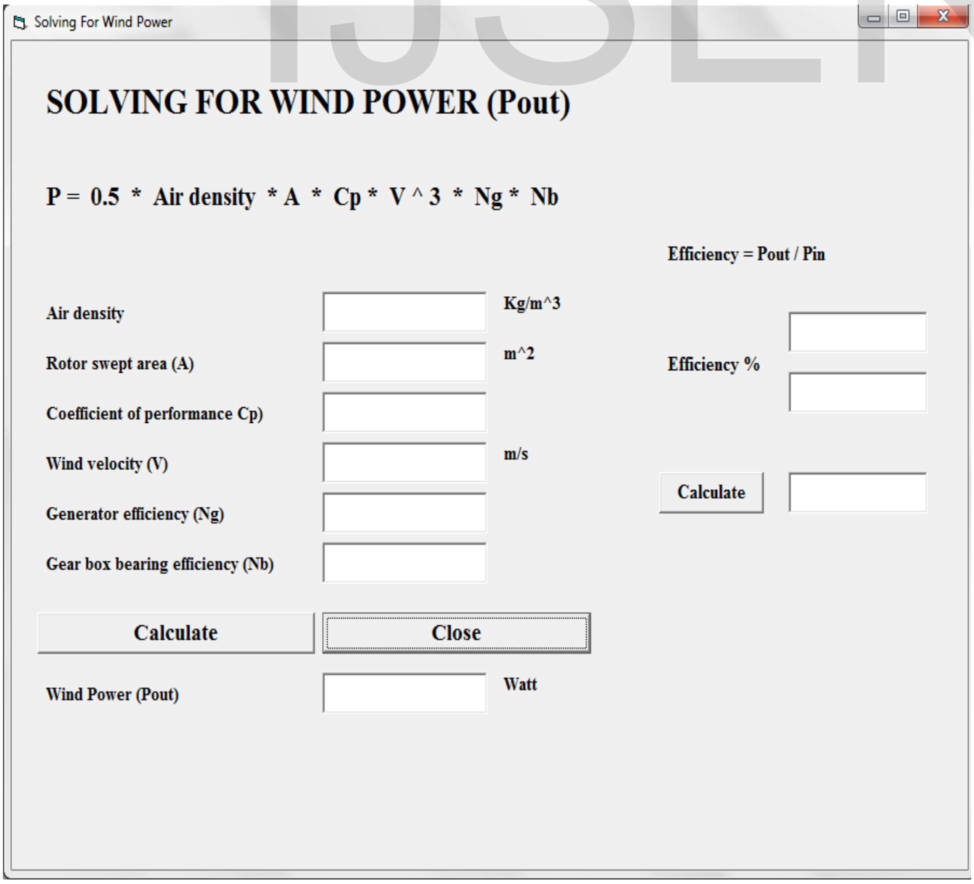
$$P_{in} = \frac{1}{2} \cdot v^3 \cdot \rho \cdot A$$

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}}$$

Time	T° ambient °c	Wind speed m/s	Humidity %	Solar intensity mw/cm^2	Power out watt	Power in watt	Voltage V	Efficiency %
09:00	25	4.2	30	66.0	8.1	59.566	5.4	13.5
09:30	26.3	4.03	30	70.4	7.77	52.62	5.29	16
10:00	28.9	4.33	20	79.2	9.9	56.27	5.97	15.5
10:30	28.9	3.98	20	79.9	8.7	50.68	5.6	17.75
11:00	29.9	3.75	20	81.5	7.51	42.39	5.2	18.14
11:30	30	4.29	20	87.2	8.04	63.47	5.38	13
12:00	31.5	3.95	20	85.0	8.4	49.55	5.5	17
12:30	31.5	4.79	20	82.0	15.6	98.70	7.5	18
01:00	32.3	5.3	20	84.3	16.9	119.69	7.8	14
01:30	33.1	5.01	20	84.0	15.62	101.104	7.5	15.37
02:00	33	4.19	20	90.0	9.66	59.14	5.9	16.58

8. Comparison and the correctness of the Mathematical module



Input values in mathematical process (imposed)

ρ	**1.2 kg/m^3**
CP	**0.55**
Ng	**0.73**
Nb	**0.95**
R	**3.6 Ω**
A	**1.34m^2**

9. Expected results from Mathematical module

Time	Wind Speed m/s	Power out Watt	Power in Watt	Efficiency %
09:00	4.2	22.70	59.566	38
09:30	4.03	.20.07	52.62	38.14
10:00	4.33	24.89	56.27	38.13
10:30	3.98	19.33	50.68	38.15
11:00	3.75	16.17	42.39	38.14
11:30	4.29	24.21	63.47	38.14
12:00	3.95	18.89	49.55	38.12
12:30	4.79	37.64	98.70	38.13
01:00	5.3	45.655	119.69	38.14
01:30	5.01	38.56	101.104	38.16
02:00	4.19	22.55	59.14	38.12

The figure (1-9) shows relation between input power, output power, efficiency and wind speed

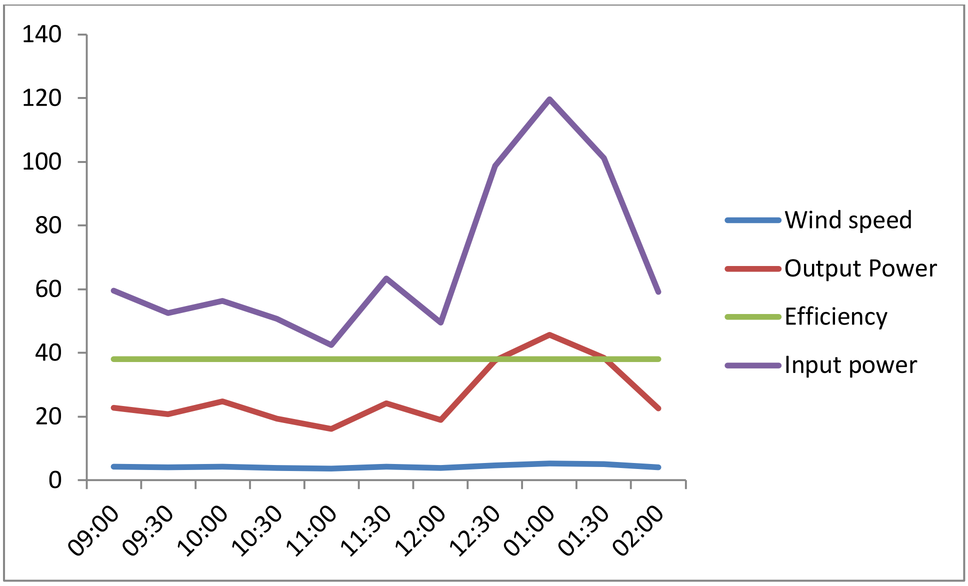


Figure (1-9)

Figure (2-9) shows relation between the Module and Experimental Efficiencies

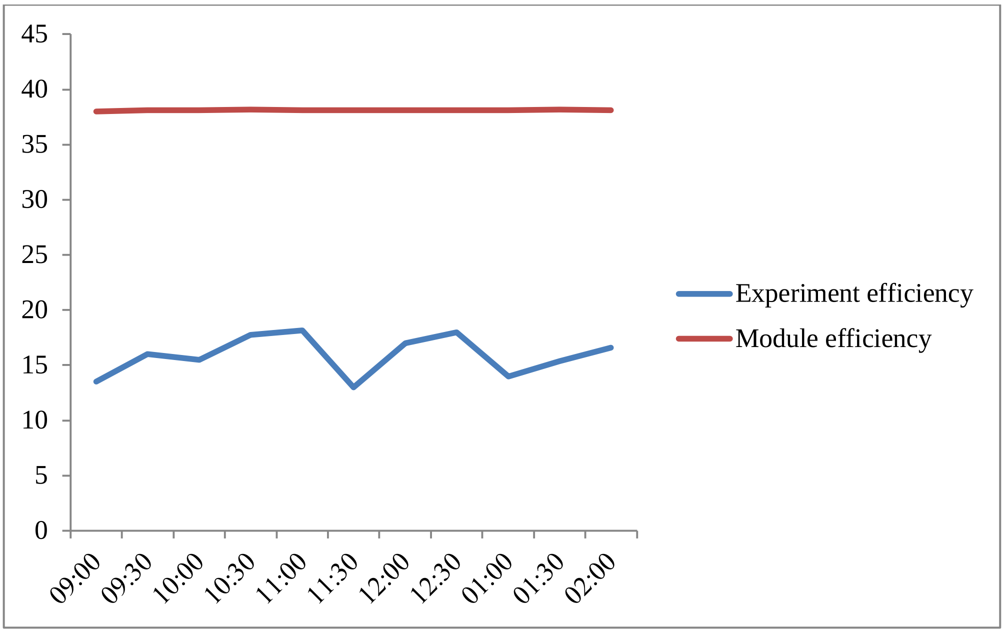


Figure (2-9)

Figure (3-9) shows the relation between output and input power

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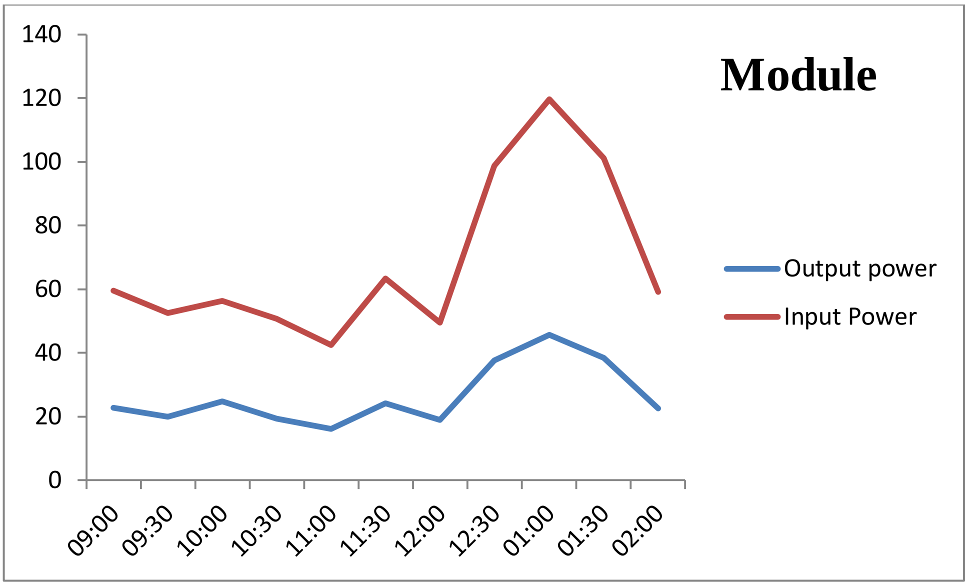

Figure (3-9)

Figure (4-9) shows relation between

Figure (4-9)

Figure (5-9) shows relation between efficiency and wind speed

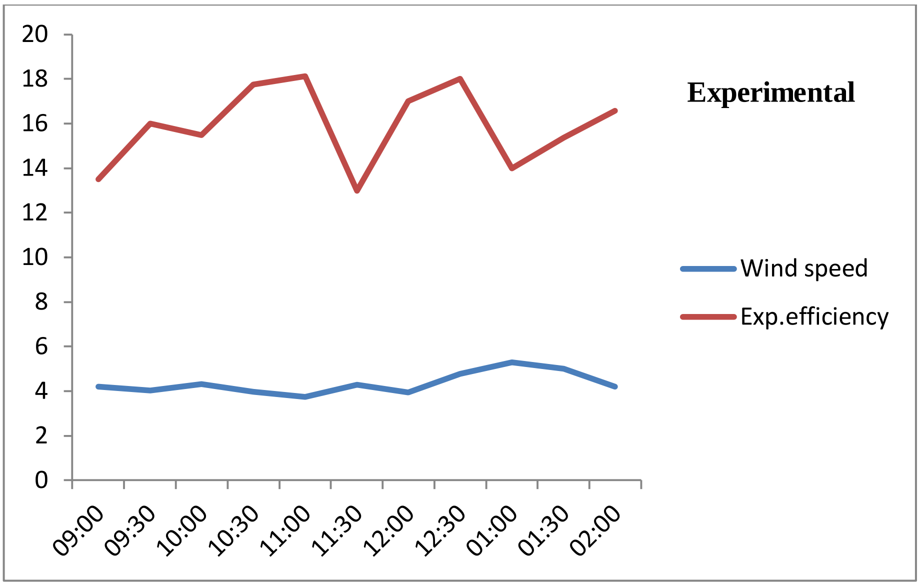

Figure (5-9)

Figure (6-9) shows relation between temperature of the ambient, humidity and Solar intensity

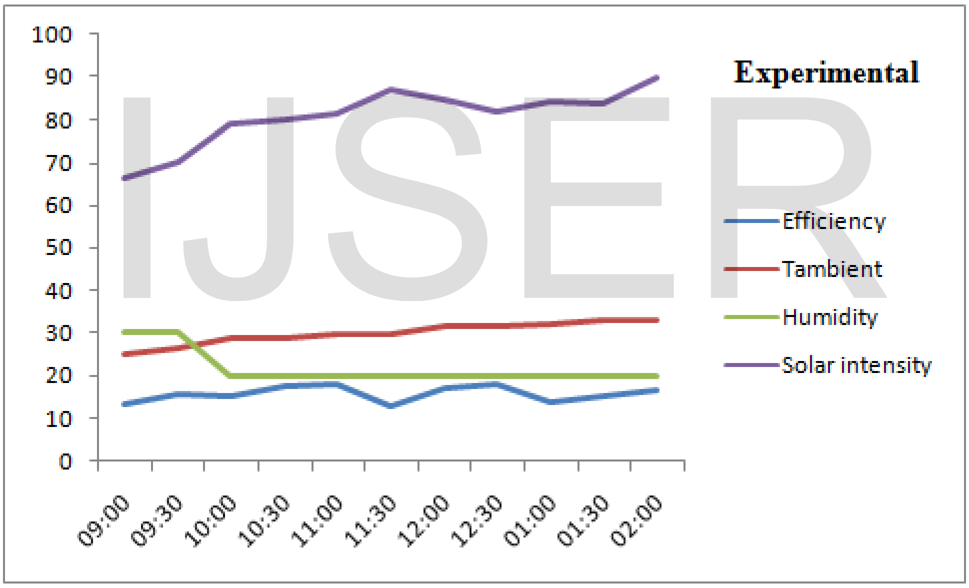

Figure (6-9)

The figure (7-9) shows relation between, voltage, wind speed, efficiency

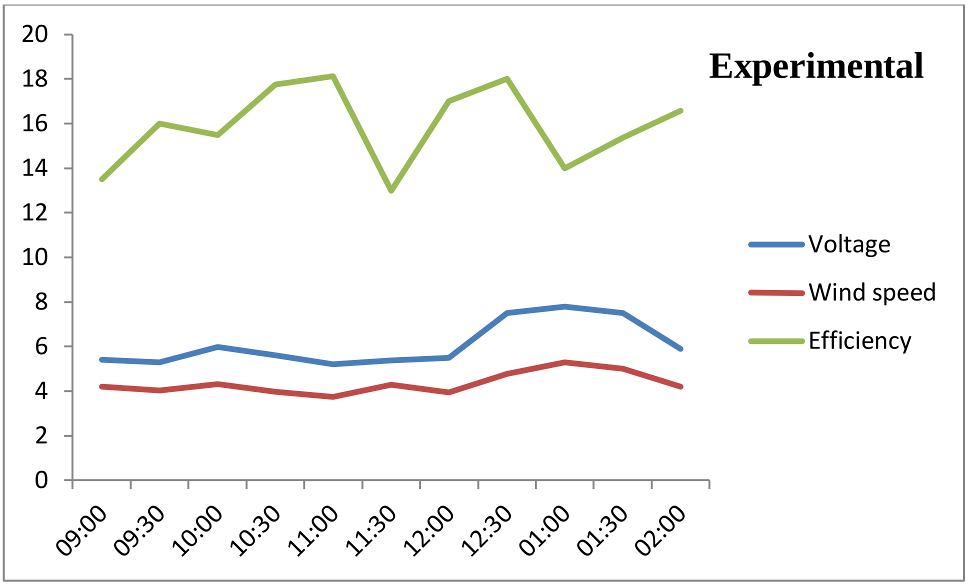

Figure (7-9)

The flowchart of the program

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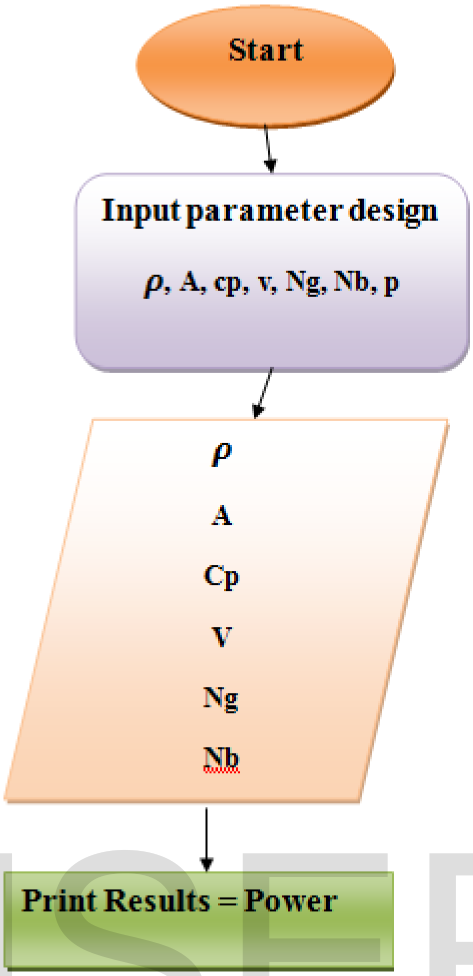

TO CALCULATE WIND POWER

Code:

```
( ) Private Sub Command1_Click
Dim r, A, cp, v, Ng, Nb, p As Single
r = Val      (Text1.Text)
A = Val      (Text2.Text)
cp = Val     (Text3.Text)
v = Val      (Text4.Text)
Ng = Val     (Text5.Text)
Nb = Val     (Text6.Text)
P = 0.5 * r * A * cp * (v ^ 3) * Ng * Nb
Text7.Text = Str (p)
End Sub
-------------------------------------
( ) Private Sub Command2_Click
End
End Sub
```

Conclusion:-

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Balancing of kinetic energy of the wind turns out that the energy derived from the use of air turbine cannot exceed more than the (0.56) of winds kinetic energy. And the linear Speed of the tip leaving the turbine equalizes 1/3 of the speed before entering the turbine. The efficiency of the turbine through test and mathematical module almost constant throughout the operating period during the day, and it doesn't affected by the value of the solar radiation during the day, because the key factor is the winds speed As a result of losses in connections laboratory as well as the lack of response by the turbine laboratory, there is a speed called operational initial speed (Cut in speed) after those looses the turbine starts to operate and increases until it reaches the consistency, so that spins at a constant speed and generation stabilized with, this speed is called the design speed (Rated speed) after this speed should underscore the turbine and must be stopped, this speed is called Cut off speed.

After this speed turbine must be stopped because if not it will be damaged, and the lack of precision with which provide simple control there appeared differences in the efficiency of accounts between Modeling and experiment on the turbine laboratory.

Through the test and modeling turns out anything as a result deserve attention It is possible to build an advanced research to refine the result and put it in the field of implementation, but which (it turns out that the energy that we can get by wind turbine increases with increasing humidity and this clear and obvious by the results of the experiment and modeling).

What is also mentioned in the above was repeated in the case of increasing air temperature less energy that is obtained by the wind turbine.

The scientific explanation for that result obtained by the experiment and modeling result is confirmed by the fact that the physical increase humidity lead to increased air mass, which increases the kinetic energy of the air.

Recommendation

We recommend, to work-up students projects and advance researches, in order to proceed in developing the work of wind turbine, by making scientific test and work-up a comprehensive field survey for Kirkuk city open areas, which will help to explore the exact places to construct wind turbine for obtaining energy form alternative clean sources and hybridized with renewable energy sources .

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