# INVESTIGATING THE PRODUCTIVE ENERGY AND THE NUMBER OF REVS OF A SMALL WIND TURBINE AT A VARIABLE WIND SPEEDS.

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**Abstract:**

In this research , the dynamics of the wind energy conversion system of a small wind turbine is studied. The aerodynamic forces are estimated at any incoming wind speeds for turbine blade which is known as airfoil section (NACA4412). The scheme is simulated by a program of Fortran90 and results are presented . The torque and the productive power are estimated from this program at each incoming wind speed, these results are compared with the extraction power from Betz theorem . Also, the number of revs of the small turbine are estimated at each incoming wind speed. From this model, we can specified the determinism of tip speed ratio and wind speed are a more suiting . Because wind speed increase over the suitable value, causes increasing of vortices of the hub and the tip and other losses .

The proposed model can further investigate for analysis, design and performance evaluation of remote and off-grid wind energy conversion systems in hybrid applications.

**Keywords:** Wind energy, Renewable energy, Aerodynamics, Small Wind turbine, (CST), Torque ,The Productive Power ,The Blade design and TSR.

# دراسة الطاقة المنتجة وعدد دورات توربين رياح صغير في سرع رياح مختلفة.

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**الخلاصة**

في هذا البحث تم دراسة ديناميكية نظام تحويل طاقة الرياح في المنظومات التوربينية الصغيرة . القوى الديناميكية الهوائية تم حسابها لأي سرعة هواء داخلة لريشة التوربين ذو المقطع الانسيابي المعروف ب(NACA4412) . وذلك من خلال اعداد برنامج محاكاة بلغة الفورتران لحساب كافة النتائج المطلوبة. أن قيمة عزم التدوير و الطاقة الناتجة من التوربين تكون محسوبة بواسطة هذا البرنامج لكل سرعة رياح داخلة إلى التوربين , حيث قورنت النتائج مع الطاقة الممتصة من الرياح المحسوبة من نظرية بيتز Betz Theorem. كذلك تم حساب عدد دورات التوربين. من خلال هذا النموذج يمكننا تحديد نسبة سرعة طرف الريشة وسرعة الرياح التصميمية الأكثر ملائمة.عندما تزداد سرعة الرياح على القيمة المناسبة فان خسائر دوامات طرف الريشة وجذرها تزداد أيضاً.

النموذج المقترح يمكن أن يتحرى لأبعد من ذلك للتحليل , وتقييم الأداء وتصميم أنظمة تحويل طاقة الرياح البعيدة وخارج الشبكة في التطبيقات الهجينة.

**Nomenclature**

| Symbols | Description | Unit |
|---|---|---|
| A | Swept rotor area | $m^2$ |
| B | Number of blades | |
| c | Chord length | M |
| $C_b$ | Betz coefficient | |
| $C_L$ | Lift coefficient | |
| $C_D$ | Drag coefficient | |
| $F1_i$ | The net force in the direction of rotation | N |
| $F2_i$ | The net force in the direction of the undisturbed wind | N |
| H | Maximum camber of airfoil | M |
| I | Area moment of inertia of blade | $m^4$ |
| $I_m$ | The mass moment of inertia of blade | $Kg.m^2$ |
| $P_{max}$ | The maximum productive power | Watt |
| r | Radius of turbine at each section | M |
| R | Maximum radius of turbine | M |
| t | The maximum thickness of airfoil, or the time | m, sec |
| T | Torque of turbine | N.m |
| TSR | Tip speed ratio | |
| $V_b$ | The blade speed | m/s |
| $V_w$ | Incoming wind speed | m/s |
| $V_{Rel}$ | Relative wind speed | m/s |
| $Z_u(x)$, $Z_l(x)$ | Function of the upper and lower surfaces of airfoil | |

**Greek Symbols**

| Symbols | Description | Unit |
|---|---|---|
| $\alpha$ | Angle of Attack | Degree |
| $\beta$ | Pitch angle | degree |
| $\varepsilon$ | Camber to chord ratio , (h/c) | |

| | | |
|---|---|---|
| $\lambda$ | Tip speed ratio | |
| $\Phi$ | Apparent wind angle, relative angle | Degree |
| $\rho_{air}$ | Air density | $Kg/m^3$ |
| $\rho_b$ | The density of blade per unit length | $Kg/m^2$ |
| $\tau$ | Thickness to chord ratio ,(t/c) | |
| $\omega$ | Angular speed of the rotor | rad/sec |

## Introduction

A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. If the mechanical energy is then converted to electricity, the machine is also called in different name a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC).The amount of power a rotor extracts from the wind can be calculated with blade element momentum theory. The power is calculated from the rotor angular velocity and torque, which are found by solving system of nonlinear equations. The system of nonlinear equations must be solved iteratively with an equation solver. The three bladed rotor is the most important and most visible part of the wind turbine. It is through the rotor that the energy of the wind is transformed into mechanical energy that turns the main shaft of the wind turbine.[ Michael,2007]

Many investigators have explored the small wind turbine using several methods to study ,analysis and modeling of the wind turbine conversion system. We can previewing these investigators and the works them , as shown below:

Khan and Iqbal, (2003) **,** in this paper dynamics of a small wind energy conversion system is modeled and simulated. Wind data generation with a flexible wind field model and the design of a fuzzy logic controller for optimum power extraction is included. Simplified models representing rotor aerodynamics are used. Control algorithm employs direct torque sensing and it adjusts rotor speed by changing the dump load. The scheme is simulated in Matlab-SimulinkTM and results are presented. Use of the proposed control algorithm removes the need for wind speed sensing with anemometers, provided a suitable torque estimation technique is available. Simulation indicates that the effect of sudden wind speed variation is minimal on the performance of a well-designed fast responding small turbine.

Daniel M. (2009) , tested different blades with various angles. He did doing this in order to discern the most efficient blade design based on voltage output. The purpose of work was to find the most efficient set of blades based on the maximum voltage that could be produced. He predicted that the composition of the rotor blades would have little or no effect on the maximum voltage output ,but gather different inertia levels that have a noticeable effect on the number of seconds it takes the blades to get to a maximum, constant voltage output and the number of seconds of revolution after the wind source is turned off. By comparing four different readings, each with a different angle, you can derive a conclusion on which angle is most effective and why. This prediction is based on the fact that angles are limited in effectiveness based on the material and size of the blades it is tested on. He found that the lighter the material was, the stronger the voltage it would output in the first five seconds, and the weaker of a voltage five seconds after the wind source was cut off. It is vice versa for heavier blades. The reason that the blades would start up faster if they were made from lighter material is because the wind force has an easier time getting a constant RPM started. This is because of the inertia, the ability of an object to store energy because of its mass.

Faizul and Quamrul Islam, [2008 ],drag and torque coefficients of a stationary five bladed vane type rotor have been investigated in this present research work by measuring the pressure distribution on the blade surfaces at various rotor angles. The experimental investigation has been performed at Reynolds number 1.65 × 105 in a uniform flow jet produced by an open circuit wind tunnel. It has been observed that the total static torque coefficient increases from 00 to 100, and reaches its maximum value and then decreases up to 300. From this point, the total static torque increases up to 72°. Total static torque coefficient at different rotor angles curve repeats from 720 to 1440, 1440 to 2160, 2160 to 2880, and 2880 to 3600 angle of rotation. A quasi-steady approach has been applied for the prediction of dynamic performance of the rotor using the static drag and torque coefficients.

Michael , [2007] , has been determined the optimal site of specific wind turbine design, which is the design that results in the lowest cost of energy at that particular site. There are many decisions that have to made in designing a modern wind turbine. The optimal wind turbine design for one location is not necessarily the optimal design for another location because the wind speed distribution may vary between locations. In addition, the turbine with the highest efficiency is not necessarily the optimal turbine. It is possible for a less efficient wind turbine to have a lower cost of energy.

Young ,and et.al ,[2007], they are under development of the prototype of 2 MW wind turbine with low speed gearbox. In this paper, the concept study for the type, the aerodynamic design for the blade and the details of load calculation will be presented. The detailed characteristics of the system will also be introduced. The rated capacity of KBP-2000M is 2000 kW with 3-blades at wind speed of 11.5 m/s and rotational speed of generator, 15.3 rpm. The power is to be produced in the range of wind speed of 3 to 25 m/s. The tip speed ratio (TSR) of rotor blade was selected as 8, in which power coefficient is 0.482, by compromising the dimensions of blades and generator with the problems related to rotational speed. The optimal TSR is maintained by torque control to get maximum wind energy under the rated wind speed. In partial load conditions under rated speed, the torque will be controlled by a predefined torque-speed curve . This torque-speed curve is chosen to achieve operation at the optimum tip speed ratio of the rotor.

Clifton-Smith and Wood, [2007], much work has been done to maximize the power extraction of wind turbine blades. However, small wind turbines are also required to be self starting and whilst blades designed for maximum power extraction can be optimized analytically, these blades often have poor starting performance. The numeric method of Differential Evolution is used here to maximize for both power and starting performance. Standard blade element theory is used to calculate the power coefficient, and a modified blade element method for starting time. The chord and twist of each blade element make up the genes for evolution. Starting times can be improved by a factor of 20 with only a small reduction in power coefficient. With the introduction of the tip speed ratio as an additional gene, up to 10% improvement in power coefficient was achieved. A second study was done in another case where analytical optimization is not possible; the inclusion of tip losses. The inclusion resulted in only a small increase in the optimum chord in the tip region which becomes less noticeable at lower tip speed ratios.

**Aerodynamics:**

Air flow over a stationary airfoil produces two forces, a lift force perpendicular to the air flow and a drag force in the opposite direction of the air flow , as shown in **Figure (1).**The pressure difference across the airfoil surfaces yields the lift force. Both the lift and the drag are proportional to the air density, the surface area of the airfoil, and the square of the wind speed. Suppose now that we allow the airfoil to move in the direction of the lift force. This motion or rotation will combine with the motion of the air to produce a relative wind direction shown in**Figure (1).** The airfoil has been reoriented to maintain a good lift to drag ratio. The lift is perpendicular tothe air flow but is not in the direction of airfoil rotation. The mathematics of Lift and Drag Forces [Gary,2001]:

$$Lift = Cl(r_{air}/2)\,A\,V_{rel}^2 \qquad (1)$$

$$Drag = Cd(r_{air}/2)\,A\,V_{rel}^2 \qquad (2)$$

Where $\mathbf{V_{rel}}$ is relative wind speed.

The lift and drag forces can be split into components parallel and perpendicular to the air flow, and these components combined to form the net force F1 in the direction of rotation and the net force F2 in the direction of the air flow. The force F1 is available to do useful work. The force F2 must be used in the design of the airfoil supports to assure structural integrity.

The way of using F1 is to connect three such airfoils or blades to a central hub and allow them to rotate around a horizontal axis, as shown in **Figure (3).** The force F1 causes a torque which drives some load connected to the propeller. The tower must be strong enough to withstand the force F2. These forces and the overall performance of a wind turbine depend on the construction and orientation of the blades. One important parameter of a blade is the pitch angle$\beta$, which is the angle between the chord line of the blade and the plane of rotation, as shown in**Figure 1**. The chord line is the straight line connecting the leading and trailing edges of an airfoil. The plane of rotation is the plane in which the blade tips lie as they rotate. The blade tips actually trace out a circle which lies on the plane of rotation. Full power output would normally be obtained when the wind direction is perpendicular to the plane of rotation. The pitch angle $\beta$ is depending only on the orientation of the blade.

Another important parameter of a blade is the relative angle$\Phi$ , which is the angle between the relative wind speed of the blade and the plane of rotation , as shown in **Figure (1).**These relations between the forces and angles, we can be regulate it in the equations below as the following

$$F1_i = L_i \sin f - D_i \cos f \qquad (3)$$

$$F2_i = L_i \cos f + D_i \sin f \qquad (4)$$

Another important blade parameter is the angle of attack , which is the angle$\alpha$ between the chord line of the blade and the relative wind or the effective direction of air flow. It is a dynamic angle, depending on both the speed of the blade and the speed of the wind. The blade speed at a distance r from the hub and an angular velocity$\omega_m$ is $r\omega_m$. The lift and drag have optimum values for a single angle of attack so maintain a nearly constant angle of attack from hub to tip. A straight blade is easier and cheaper to build and the cost reduction may more than offset the loss in performance.[7]

**The Aerodynamic Profile**

The shape of the aerodynamic profile is decisive for blade performance. Even minor alterations in the shape of the profile can greatly alter the power curve and noise level. Therefore a blade designer does not merely outline the shape when designing a new blade. The shape must be chosen with great care on the basis of past experience. For this reason blade profiles were previously chosen from a widely used catalogue of airfoil profiles developed in wind tunnel research by NACA.[ Stiesdal,1999]

**Blade Design**

To create a blade design we need to specify the chord width and relative angle$\Phi$ at each of a series of stations along the span of the blade. At each station we will create the right shape of the blade to produce the right loading (Lift) for the bit of wind with which it will have to deal. The tip speed ratio is the ratio between the speed of the wind and the speed of the tips of the blades of a wind turbine. High efficiency 3-blade-turbines have tip speed/wind speed ratios of 6 to 7. Modern wind turbines are designed to spin at varying speeds (a consequence of their generator design). Use of aluminum and composites in their blades has contributed to low rotational inertia, which means that newer wind turbines can accelerate quickly if the winds pick up, keeping the tip speed ratio more nearly constant. Operating closer to their optimal tip speed ratio during energetic gusts of wind allows wind turbines to improve energy capture from sudden gusts that are typical in urban settings. In contrast, older style wind turbines were designed with heavier steel blades, which have higher inertia, and rotated at speeds governed by the AC frequency of the power lines. The high inertia buffered the changes in rotation speed and thus made power output more stable. [ David,2002]

**1-Setting The Test Blade Angle.**

When design a wind turbine rotor ,the angle $\alpha$ will depend on the angle of the apparent wind $\phi$ ,and the pitch angle $\beta$ .So we have control over $\alpha$ ,and thus control over the lift and drag produced by the blade .We shall need to optimize the lift force ,to satisfy the Betz criterion, but the blade will not work well unless the drag is minimized. We can say that the relative angle $\Phi$ should be set to give this angle of attack. To specify the pitch angle $\beta$ , we need to know the relative angle $\Phi$ at which the relative wind strikes the rotor plane.[ David,2002]

$$f = b + a \qquad (5)$$

$$f = \tan^{-1}\left(\frac{2R}{3r * TSR}\right) \qquad (6)$$

**2-Moment of Inertia of Airfoil Sections**

The moment of inertia of the airfoil cross-sections about the axis x is then related only to the airfoil shape given by the upper and lower surfaces Zu(x) and Zl(x). As shown in **Figure (2)**, both the area (A) and the total moment of inertia I are the integrated contributions of all the infinitesimal rectangular sections, each dx wide and Zu − Zl tall. The inertia of each such section is appropriately taken about the neutral surface position $\bar{z}$ defined for the entire cross section.[10]

$$A_i = \int_0^c [Z_u - Z_l]_i\, dx \qquad (7)$$

$$\bar{z}_i = \frac{1}{A_i}\int_o^c \frac{1}{2}[Z_u^2 - Z_l^2]_i\, dx \qquad (8)$$

$$I_i = \int_0^c \frac{1}{3}[(Z_u - \bar{z})^3 - (Z_l - \bar{z})^3]_i\, dx \qquad (9)$$

These relations which is a good assumption if the x axis is parallel to the airfoil's chord line. Although equations (7) –(9) can be numerically evaluated for any given airfoil, this is unnecessarily cumbersome for preliminary design work, where both ( A ) and ( I ) are needed for possibly a very large number of candidate airfoils or wings .For the purpose of approximating ( A ) and ( I ), we first define the maximum thickness t, and maximum camber h, in terms of the upper and lower surface shapes. We also define the corresponding thickness and camber ratios $\tau$ and $\varepsilon$. [10]

$$t = \max\{Z_u(x) - Z_l(x)\} \qquad (10)$$

$$h = \max\{[Z_u(x) + Z_l(x)]/2\} \qquad (11)$$

$$t \equiv t/c \qquad (12)$$

$$e \equiv h/c \qquad (13)$$

Examination of equation (7) indicates that ( A ) is proportional to (t and c), and examination of equation (9) indicates that ( I ) is proportional to [ c and t ($t^2 + h^2$)]. This suggests estimating ( A ) and ( I ) with the following approximations [10].

$$A_i = KA_i \times c \times t \qquad (14)$$

$$A_i = KA_i \times c^2 \times \tau \qquad (15)$$

$$I_i = KI_i \times c \times t(t^2 + h^2) \qquad (16)$$

$$I_i = KI_i \times c^4 \times \tau(\tau^2 + \varepsilon^2) \qquad (17)$$

The proportionality coefficient can be evaluated by equating the exact and approximate ( A) and (I) expressions above, e.g. [10].

$$KA_i = \frac{1}{c^2 \times \tau}\int_0^c [Z_u - Z_l]_i\,dx \qquad (18)$$

$$KI_i = \frac{1}{c^4 \times \tau(\tau^2 + \varepsilon^2)}\int_0^c \frac{1}{3}[(Z_u - \bar{z})^3 - (Z_l - \bar{z})^3]_i\,dx \qquad (19)$$

**3-Selecting Blade Chord and Profile.**

The width of the blade is also called the blade chord. A good formula for computing this is:

$$C = 2.793\frac{R^2\cos(f)}{B * TSR^2\, r(C_L + C_D\tan(f))} \qquad (20)$$

Many of the good profile data can be found in literatures of model airplane. We have chosen the NACA 4412 profile. It is an effective profile with a good thickness, which makes the blade strong. In order to determine the lift coefficient, we must have a look at the profile curves.In order to determine the lift coefficient we must have a look at the profile curves[David,2002]

**Blade Element Momentum Theory.**

The amount of rotor power which extracts from the wind can be calculated with blade element momentum theory. The power is calculated from the rotor angular velocity and torque, which are found by solving system of nonlinear equations. These equations are derived from two different approaches to calculating power. The first approach determines the power from lift and drag on the rotor blades. The second approach determines power from a momentum balance.

**Dynamic Modeling**

**1- Wind Field**

Investigation of wind turbine performance require a realistic set of wind data with durations ranging form minutes to hours. We assumed the constant the incoming wind speed for calculation of torque and the power.At each station we will create the right shape of blade to produce the right loading lift for bit of wind with which it will have to deal with. The bit of the blade at radius **r** sweeps a fraction of the total swept area and has the job of slowing this bit of wind down by the right amount to satisfy the Betz criterion ,see **Figure (3)**. The apparent wind which a blade is altered by it 's own speed through the air. The rotational wind speed adds to the incoming wind speed to give the relative wind speed which creates the lift and drag forces. [Khan and Iqbal,2003].

$$V_{Rel} = \sqrt{(V_W)^2 + (V_{Ro})^2} \qquad (21)$$

$V_{Ro}$ is the blade speed at a distance r from the hub and an angular velocity ω is :

$$V_{Ro} = r\,\omega \qquad (22)$$

**2- Aerodynamics Forces:**

The aerodynamics forces (Lift and Drag forces) depend on the coefficients **Cl** and **Cd,** which in turn depend on the cross section of blade we are using and on the angle **α** at which the wind strikes the blades. The lift and drag coefficients are obtained from tables. These are experimentally measured in wind tunnels and recorded For the NACA 4412 this point of contact is where **Cl** is about (0.933) degrees and Cd is about (0.037) at **α** is about 8 degrees and low Reynolds number [Khan and Iqbal,2003]:

The lift and drag forces of the aerofoil are estimated from Equations ( 1 and 2) respectively

**3- Torque & Thrust by Lift & Drag**

The power is calculated from the rotor angular velocity and torque, which are found by solving system of nonlinear equations ( 1 & 2 ) ,these forces effecting on the airfoil sections of the blade from the hub to the tip, as shown in **Figure (3)** and equations ( 3 and 4 ).[ Michael,2007]

A practical way of using F1 is to connect three blades to a central hub and allow them to rotate around a horizontal axis. The force F1 causes a torque which drives some load connected to the propeller along the blade from the hub to the tip:

$$T_i = F1_i \times (r + dr/2) \qquad (23)$$

Where $T_i$ is the torque due to the wind speed at each station on the blade .The summation of the above torque along the blade represent the torque for the one blade. The total torque is the summation of all the torque of blades at the wind turbine for any the incoming wind speed . We assume the wind turbine design consists of three blade . Therefore;

$$\text{Total Torque, ( T ) } = 3 \times \sum T_i \qquad (24)$$

**4-Determination of Rotor Speed**

For determining the rotor speed from an estimated the rotor torque could be established from the basic principles of wind energy engineering. The turbine torque $T_{j+1}$ must be opposed by an equal and opposite load torque $T_j$ for the turbine to operate at a steady rotational speed. If $T_{j+1}$ is greater than $T_j$ , the turbine will accelerate, while if $T_{j+1}$ is less than $T_j$ the turbine will decelerate. The mathematical relationship describing this is:

$$T_{j+1} = T_j + I_m \frac{dw}{dt} \qquad (25)$$

Where, $I_m$ is the mass moment of inertia of the turbine, all referred to the turbine shaft.

$$I_m = r_b \times I \qquad (26)$$

$\frac{dw}{dt}$ is angular acceleration of the turbine .

Since the acceleration is ( dω/dt ) , we can determine that the angular velocity of the turbine must increase linearly with time until the turbine reaches its rated angular velocity .

$$dw = \left( \frac{T_{j+1} - T_j}{I_m} \right) dt \qquad (27)$$

**5- Estimated Power.**

The maximum productive power from wind $P_{max}$ could be found by multiplying maximum Torque $T_{max}$ with rotor speed, ω for any incoming wind speed:

$$P_{max} = T_{max} \times w \qquad (28)$$

We can be calculate the power and the revolution of the rotor for the wind turbine for any incoming wind speed by using the computer program.

**6-Determination of Tip Speed Ratio:**

The tip speed ratio (TSR) $\lambda$ is a measure of the rotor's rotational speed at any given wind speed, where , (TSR) $\lambda$ =(tip speed of blade)/(incoming wind speed).

$$TSR = \frac{R \times w}{V_w} \qquad (29)$$

**Results and Discussion :**

Fortran power station program is used for simulating the models ,the flow chart of the mathematical model programming as shown in the **Figure ( 4 ).** The inputs to the model are an incoming wind speed, aerodynamic coefficients ( lift and drag ) of the airfoil for NACA-4412 , the airfoil section with all dimensions ,angle of attack $\alpha$, which is constant for all values of "r" ,the relative angle $\Phi$ and pitch angle $\beta$ at each station and rotor diameter, see **Table ( 1 )** [Humaid and Ali,2005]. The outputs of the program model are revealed in the **Table ( 2 )** .

**Figure ( 5 )** shows the aerodynamic maximum torque compare with the startup aerodynamic torque at any incoming wind speed. As the incoming wind speed increase , the lift forces increase ,along the blades from hub to tip, consequently the maximum torque increase, also the startup torque increase with increase the incoming wind speed at startup which prevailing the mass moment of inertia of blades.

The Maximum power produce by torque element compare with Betz coefficient Theorem are presented as a function of the incoming wind speed in **Figure ( 6** ).The Power Produce by Betz coefficient theorem is estimated from the below equation[Gary,2001]:

$$\text{Power (W)} = \rho_{air}/2 \times C_B \times A \times (V_w)^3 \qquad (34)$$

$C_B$ = Betz coefficient ( 0.59)
$\rho_{air}$ = the air density (1.2 kg/m$^3$).
A = Swept rotor area (m$^2$)
$V_w$ = Wind speed (m/s)

The max. tip speed ratio and max. revolution per second are presented as a function of the incoming wind speed in **Figure ( 7 ).** We can see the increase of the TSR when the incoming wind speed increase until the wind speed reaches to 9 m/sec where the increase in TSR become very large ,where reach about (24.22 ) in the wind speed (20 m.sec).

**Conclusions:**

1-The choice of tip speed ratio TSR depends on many factors . High tip speed ratio results in higher shaft speed is more efficient for generating electricity which often outweighs the following disadvantages :

- Noise from the blades is higher ;
- Starting difficulties if the shaft is stiff to turn.
- Blades edges at high air -speeds suffer erosion;
- Reduced rotor efficiently due to drag and tip vortex loss ;

2-From same figures below it is clearly noticed that the increase the incoming wind speed (above 9m/sec.) causes increase of loss of the hub and tip vortex which causes loss in the power output [9], but the program don't calculate loss of the hub and tip vortex ,as shown in the **Figures ( 6 & 7 )** , where we can notice that the productive power larger than the maximum extraction power from Betz theorem.

3-The turbine rotor with tip speed ratio 5.901 in a 9 m/s wind speed or a (4 m) diameter rotor running at (5.494 rev/sec) will be at the safer work. But, the working at tip speed ratio above 6m/sec the turbine rotor will be at risk from blade erosion. The effect increases dramatically as the speed increases.

4-Also, we can specifying the productive power , tip speed ratio and revolution of second of the small wind turbine under the studying as the following ( 2716.122 Watt , 5.901 and 5.494 rev/sec). respectively.

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Table ( 1 ): Dimensions of blade under study at each section for NACA-4412 airfoil [12].

| Section # | r (m) | Chord width (mm) | Φ (degree) | β (degree) |
|---|---|---|---|---|
| 0 | 0.2 | 377.04 | 22.50 | 14.50 |
| 1 | 0.25 | 335.64 | 19.33 | 11.33 |
| 2 | 0.3 | 299.55 | 16.85 | 8.85 |
| 3 | 0.4 | 243.06 | 13.28 | 5.28 |
| 4 | 0.5 | 202.63 | 10.90 | 2.90 |
| 5 | 0.6 | 172.98 | 9.22 | 1.22 |
| 6 | 0.7 | 150.56 | 7.97 | -0.03 |
| 7 | 0.8 | 133.10 | 7.02 | -0.98 |
| 8 | 0.9 | 119.18 | 6.26 | -1.74 |
| 9 | 1 | 107.84 | 5.65 | -2.35 |
| 10 | 1.1 | 98.43 | 5.15 | -2.85 |
| 11 | 1.2 | 90.51 | 4.73 | -3.27 |
| 12 | 1.3 | 83.76 | 4.37 | -3.63 |
| 13 | 1.4 | 77.94 | 4.07 | -3.93 |
| 14 | 1.5 | 72.86 | 3.80 | -4.20 |
| 15 | 1.6 | 68.40 | 3.56 | -4.44 |
| 16 | 1.7 | 64.45 | 3.35 | -4.65 |
| 17 | 1.8 | 60.93 | 3.17 | -4.83 |
| 18 | 1.9 | 57.78 | 3.00 | -5.00 |
| 19 | 2 | 54.93 | 2.86 | -5.14 |

Table ( 2 ): Results of the model, (The outputs of the program model).

| Max. Torque(N.m) | Startup Torque(N.m) | TSR | No.(RPS) | Power(Watt) | Power(Betz) | $V_w$(m/s) |
|---|---|---|---|---|---|---|
| 1.372396 | 0.222 | 1.71E-01 | 1.77E-02 | 3.725819 | 1.52E-01 | 1 |
| 5.944182 | 0.889 | 3.70E-01 | 7.65E-02 | 29.806552 | 2.856441 | 2 |
| 16.54393 | 2 | 6.86E-01 | 2.13E-01 | 100.597113 | 22.12679 | 3 |
| 25.47769 | 3.555556 | 2.6407 | 1.09273 | 238.452416 | 174.9202 | 4 |
| 35.53966 | 5.555555 | 2.946878 | 1.524284 | 465.727375 | 340.3661 | 5 |
| 43.53198 | 8 | 3.456914 | 2.145723 | 804.776904 | 586.8798 | 6 |
| 49.45377 | 10.88889 | 4.131115 | 2.99157 | 1277.955917 | 929.5349 | 7 |
| 52.58567 | 14.22222 | 4.949636 | 4.09635 | 1907.619328 | 1353.417 | 8 |
| 55.66201 | 18 | 5.901451 | 5.494588 | 2716.122051 | 1921.592 | 9 |
| 61.84668 | 22.22222 | 6.979943 | 7.220807 | 3725.819 | 2805.88 | 10 |
| 68.03135 | 26.88889 | 8.180903 | 9.309531 | 4959.065089 | 3979.275 | 11 |
| 74.21602 | 32 | 9.501527 | 11.79529 | 6438.215232 | 5500.132 | 12 |
| 80.40069 | 37.55556 | 10.93987 | 14.71259 | 8185.624343 | 7432.178 | 13 |
| 86.58536 | 43.55556 | 12.49454 | 18.09598 | 10223.64734 | 9844.499 | 14 |
| 92.77003 | 50 | 14.16452 | 21.97997 | 12574.63913 | 12811.55 | 15 |
| 98.95468 | 56.88889 | 15.94906 | 26.39909 | 15260.95462 | 16413.16 | 16 |
| 105.1394 | 64.22222 | 17.84756 | 31.38786 | 18304.94875 | 20734.52 | 17 |
| 111.324 | 72 | 19.85958 | 36.98081 | 21728.97641 | 25866.18 | 18 |
| 117.5087 | 80.22222 | 21.98475 | 43.21245 | 25555.39252 | 31904.06 | 19 |
| 123.6934 | 88.88889 | 24.22278 | 50.11732 | 29806.552 | 38949.45 | 20 |

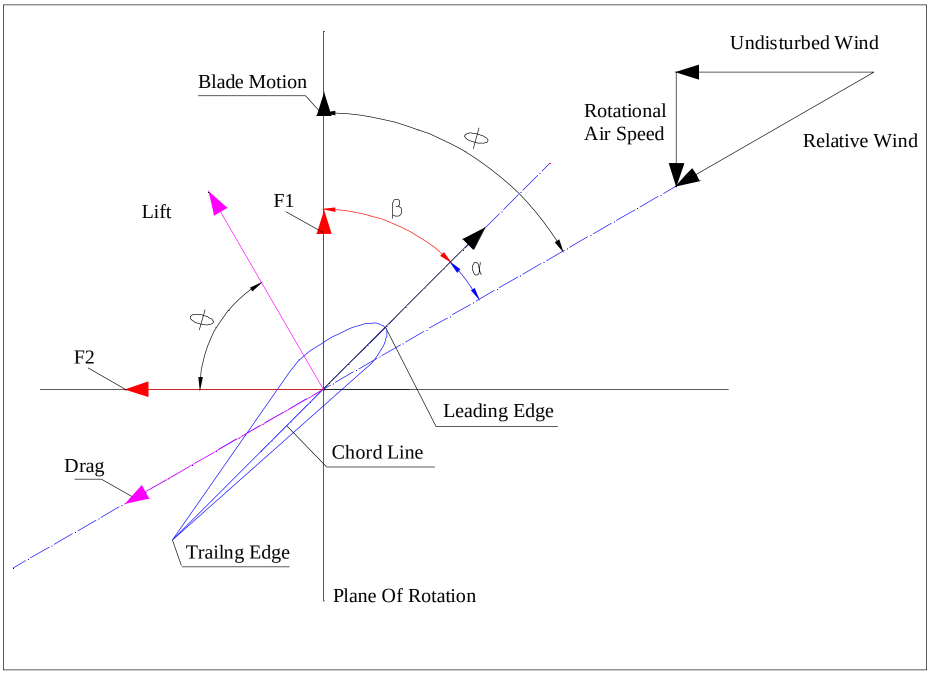
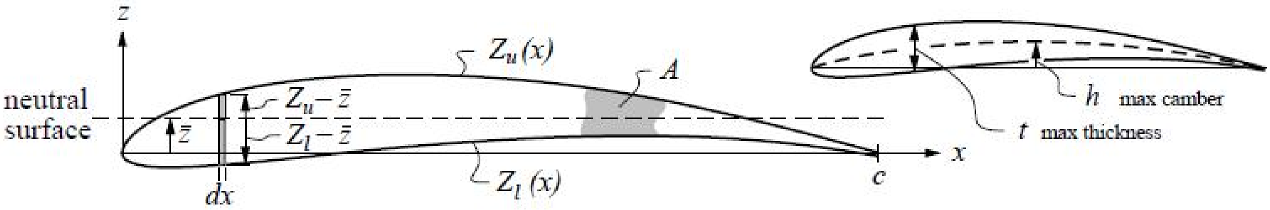



Figure (1):Definitions of pitch angleβ ,angle of attack α and all forces and velocities on a translating airfoil.




Figure(2): Quantities for determining and estimating the inertia of an airfoil section [10].

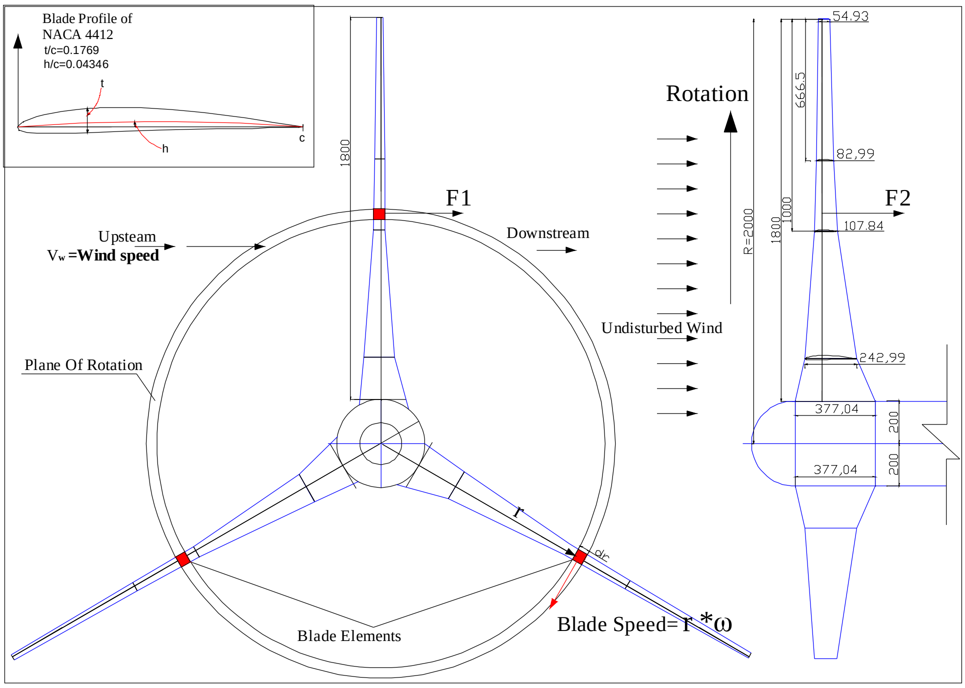



Figure ( 3 ):The wind turbine blades with incoming wind speed and effective forces .

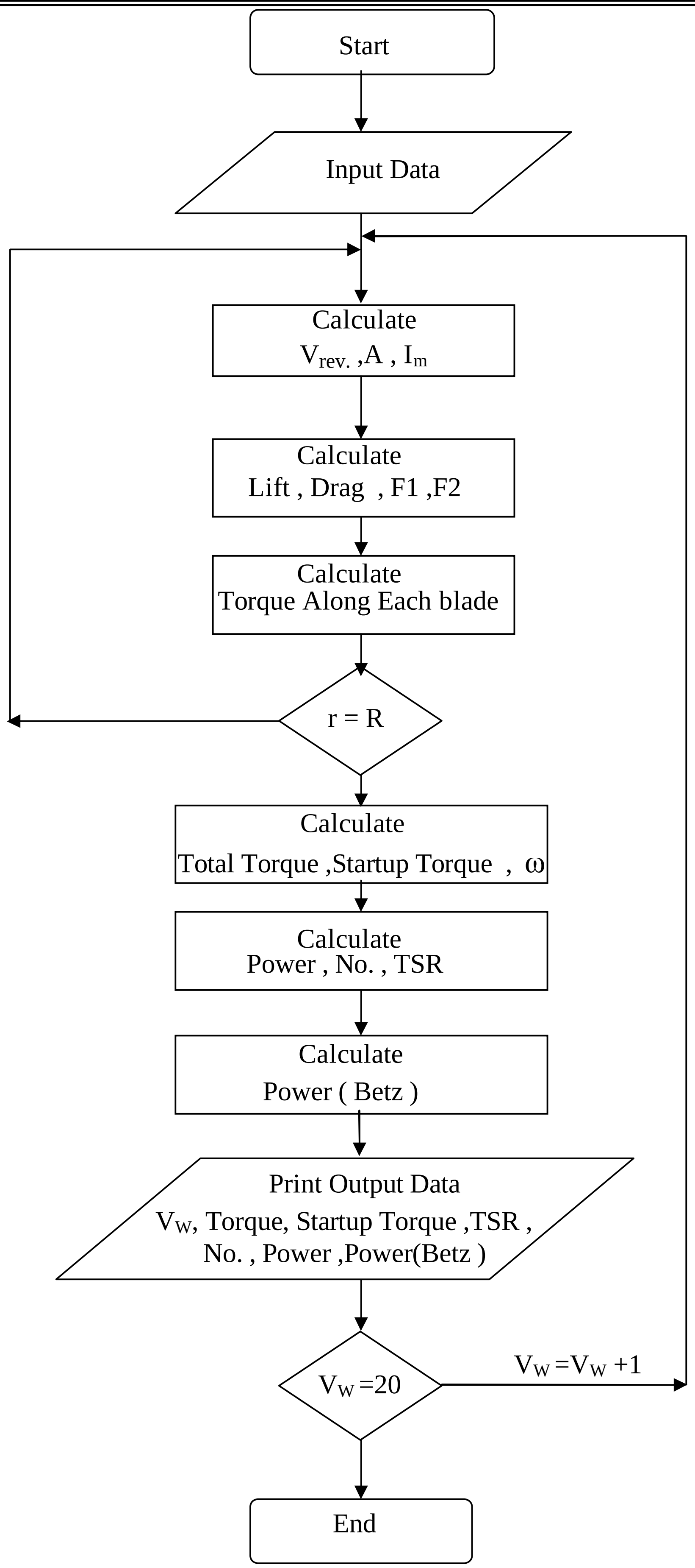



Figure (4): Flow Chart of Fortran power station program.

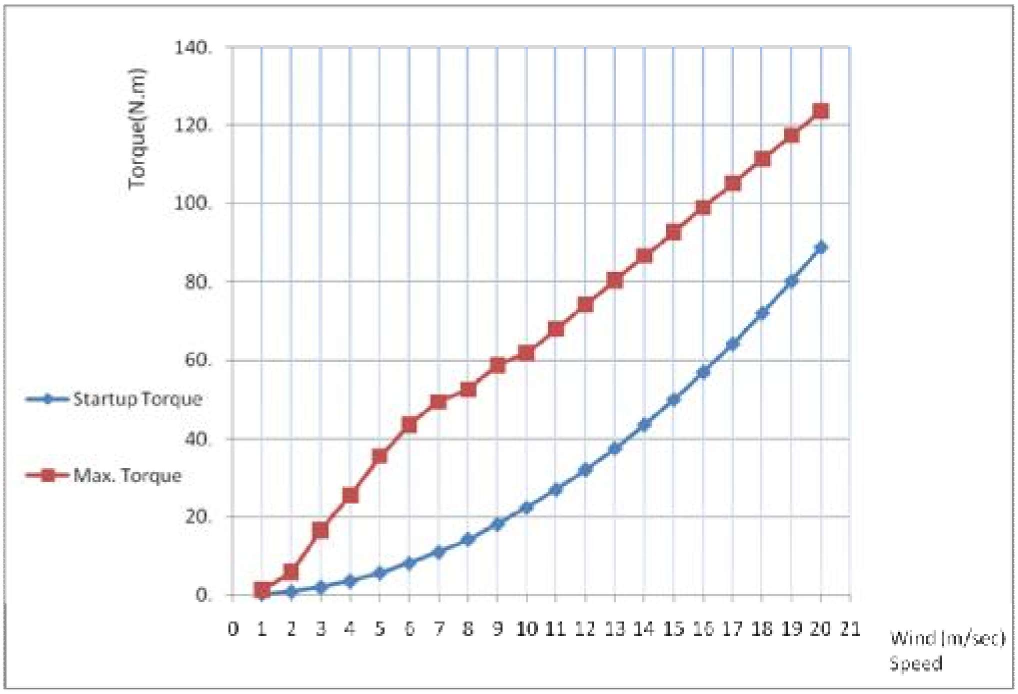



Figure (5): Max. Torque Load and Startup Torque at any Wind Speed.

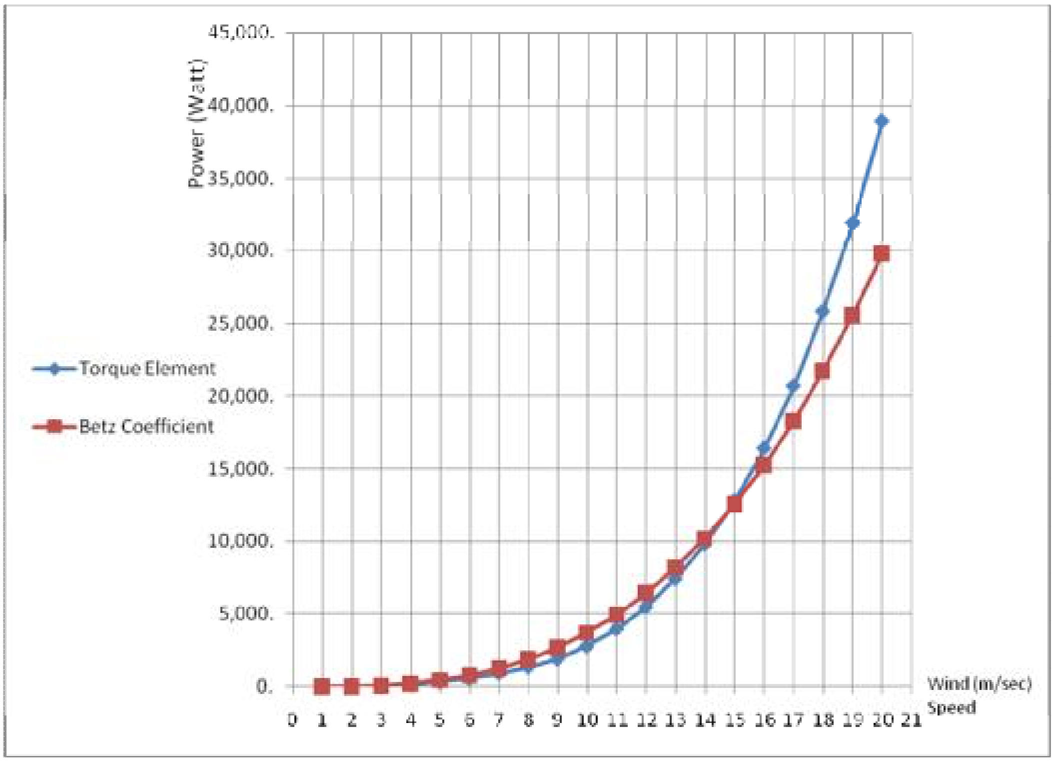



Figure (6): Max. Power Produce by torque element compare with Betz coefficient Theorem at any Wind Speed.

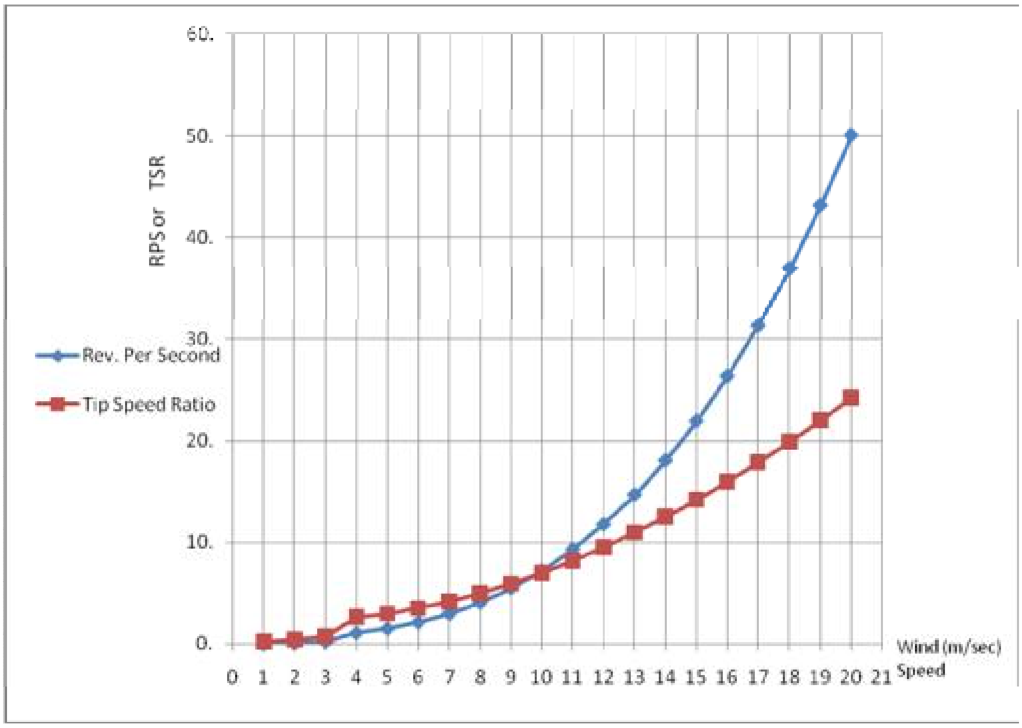



Figure (7): Max. Tip Speed Ratio and Max. Revolution Per Second at any Wind Speed.