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COMPUTER PROGRAM TO PREDICT PERFORMANCE OF FAST RUNNING HORIZONTAL AXIS WIND TURBINE TO REACHING THE OPTIMUM DESIGN

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ABSTRACT:- A computer program in visual basic was designed to predict the performance of fast running horizontal axis wind turbine for electricity generation by using blade element theory and momentum theory. NACA 4415 was chosen for the aerofoil section of blade. the design parameters (design tip speed ratio , rotor radius and blade number) represented in scroll bars was designed in visual basic, and by changing these parameters , solidity, chord line and twist angle curves along the blade, in addition to the rotor performance curve (relation of power coefficient with tip speed ratio), will be draw instantly.

The numerical integration (trapezoidal method) was used to compute the area under rotor performance curve, the program will record the value of this area, and by change parameter design and by knowing the maximum value of area, we will know the optimal design for turbine rotor.

The three and four rotor blades and the values of design tip speed ratio between (5 - 9) give the best performance of rotor. The effect change of rotor radius on performance rotor was found very small, and there is no noticed effect to rated wind speed on rotor performance when changing parameter design in computer program.

Keywords: wind rotor, wind turbine, fast running HAWT, optimum design, performance prediction method, NACA 4415.

NOMENCLATURE

Symbols	Description	Units
A	Rotor swept area	m^2
a , a'	Axial and tangential interference factor	-
B	number of blade	-
BET	Blade Element Theory	-
C	profile chord for blade	m
C_A , C_T	Axial and tangential force factors	-
C_D , C_L	Drag and Lift coefficients	-
C_{LD}	Design lift coefficient	-
C_p	Power coefficient	-
C_q	Moment coefficient	-
D	Drag force	N
L	Lift force	N
d	Rotor diameter	m
df_{b1}	Local axial force from BET	N
df_{Amon}	Local axial force from momentum theory	N
dQ_{b1}	Local moment from BET	N.m
dQ_{mom}	Local moment from momentum theory	N.m
dr	blade element width	m
E , G	Dimensionless factors for axial and tangential interference factors	-
HAWT	Horizontal Axis Wind Turbine	-
m_r	Local momentum coefficient for blade station	-
n	Numbers of revelation of rotor per minute (rpm)	rpm
R	Radius of turbine rotor	m
r	Local Radius of turbine rotor	m
r/R	Radial ratio	-
TSRd	Design Tip Speed Ratio in graphs and equal to (λ_d)	-
V	Wind speed	m/s
V_r	Rated wind speed	m/s
Ω	angular velocity	rad/s
α	Angle of Attack	Degree
φ	Aerofoil relative angle	Degree
ρ	Air density	kg/m^3
η_b	Prandtal efficiency	-
λ	Tip Speed Ratio	-
λ_d	Design Tip Speed Ratio	-
λ_r	Local tip speed ratio	-
σ	Solidity	-
F_T, F_A	Tangential force, Axial force	N
D_T,D_A	Tangential and Axial Drag	N
L_T,L_A	Tangential and Axial Lift	N
ω	Air rotational speed when it pass through the rotor	

INTRODUCTION

The wind is natural phenomenon related to the movement of air passes caused primary by differential solar heating of the earth surface. Most wind turbine blades where adaptations of airfoils developed for aircraft and were not optimized for wind turbine uses. In recent years developments of improved airfoil sections for wind turbines have been going. That may have modifications in order to improve performance for special applications and wind conditions. To gain high efficiency, the blade is both tapered and twisted. The taper, twist and airfoil characteristic should all be combined in order to give the best possible energy capture for the rotor speed and site conditions(1).

Milborrow and Ainslie (2) used a streamline curvature technique for calculation of flow pattern performance prediction. The power coefficients obtained through this method at high rotor loadings were higher than those obtained through momentum considerations. R Lanzafame and Messina(3) used the blade element momentum theory to obtain maximum electrical energy output for a rotor with two blades, with a 10m diameter, in a given wind site. Yukio Watanabe(4) used the boundary element method (BEM) to evaluated the maximum the C_p of a horizontal axis wind turbine (HAWT) blade operating in low Reynolds number range less than 10^6. Florin Iov (5) used four simulation tools namely: HAWC, DIgSILENT, Saber and Matlab /Simulink platform for modeling, optimizing and designing wind turbines system. These models can be easily extended to model different kinds of wind turbines or even large wind farms. The performance of these models is proven and they can be directly implemented in different simulation tools.

In this paper, the design optimization was obtained for fast running wind turbine rotor by using blade element theory and momentum theory to compute the area under the curve (C_p -λ) to get optimal value power coefficient as a function of tip speed ratio.

THE DESIGN PARAMETERS

Airflow over a stationary airfoil produces two forces, a lift force perpendicular to the airflow and a drag force in the direction of airflow, the existence of the lift force depends on laminar flow over airfoil, when the airfoil is move in direction of the lift this translation will combine with the motion of the air to produce a relative wind direction (W), the airfoil has been reoriented to maintain a good lift to drag ratio. The lift (L) and drag (D) forces can be split into components parallel and perpendicular to the direction of the undisturbed wind. The lift is perpendicular to the relative wind but is not in the direction of airfoil translation, and these components combined to form the tangential force (F_T) and axial force (F_A). The tangential force (F_T) acting on the turbine rotor in the direction of translation which is available to do useful work ; and allow for the blades to rotate around to a horizontal axis and causes a torque that drive some load connected to the turbine rotor as shown in Fig.(1). The other force is axial force (F_A) on the direction of the undistributed wind which must to be used in the design of the airfoil supports to assure structural integrity, and the tower must be strong enough to withstand this force.

One important parameter of a blade is pitch angle (twist angle) see Fig. (2), which is the angle between the chord line of the blade and plane of rotation. 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 that 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 is a static angle, dependent only on the orientation of the blade. Another important parameter is the angle of attack, which is the angle between the chord line of the blade and the relative wind or the effective direction of airflow it is a dynamic angle, depending on both the speed of the blade and the speed of the wind, The other important parameters will be list as following in bolt font. (5)

Rated wind speed (V_r) is the wind speed which mechanical power of turbine reaches to maximum value. Rotor radius, (R) it is the distance from centre of the hub to the tip of blade, and with increase rotor diameter increases the wind power, because the rotor swept area will increase. Tip Speed Ratio (λ) is the dimensionless ratio of the tip speed to the upstream wind speed (V), $\lambda = \frac{R.\Omega}{V}$ ----------------------------- ----(1)

Where angular velocity $\Omega = \frac{2\pi n}{60}$ --(2)

Design tip speed ratio(λ_d) it is the value which power coefficient reach to approximate to optimal value and it's a useful measure for comparison of different wind turbine designs; it is one very important parameter for all types of rotodynamic machines. Blade number (6), the determination of the number of blades involves design considerations of aerodynamic efficiency (power coefficient), component costs, system reliability, and aesthetics. Noise emissions are affected by the location of the blades upwind or downwind of the tower and the speed of the rotor, given that the noise emissions from the blades' trailing edges and tips vary by the 5th power of blade speed, a small increase in tip speed can make a large difference. Aerodynamic efficiency increases with number of blades but with diminishing return. Increasing the number of blades from one to two yields a six percent increase in aerodynamic efficiency, whereas increasing the blade count from two to three yields only an additional three percent in efficiency. Further increasing the blade count yields minimal improvements in aerodynamic efficiency and sacrifices too much in blade stiffness as the blades become thinner. Finally, aesthetics can be considered a factor in that some people find that the three-bladed rotor is more pleasing to look at than a one- or two-bladed rotor. shape of blade. (7), the blades are defined at a number of 'stations' as shown in Fig.(3). each station has a 'local radius', for each station there is a 'chord width'.

POWER COEFFICIENT

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given the symbol C_p standing for the coefficient of performance which is not a constant, but varies with the wind speed, the rotational speed of the turbine, and turbine blade parameters such as angle of attack and twist angle. The HAWT have variable twist angle ,the twist angle is varied to hold power coefficient at its largest possible value up to the rated speed of the turbine, designing the blades to have a maximum coefficient of performance bellow the rated wind speed helps to maximize the energy production of the turbine(5).

PERFORMANCE PREDICTION METHOD USED IN PRESENT WORK

Conventional analysis of the performance of a HAWT rotor combines a momentum balance of the flow upstream and downstream of the rotor with the aerodynamic characteristics of the airfoil section concerned. The momentum theory and the blade element theory yields the following relationships for elemental thrust and torque (8) (9) (10) (11) (12).

$dQ_{mom} = \omega r^2 dm = 4\pi\rho V\Omega(1-a)a'.r^3.dr$ ------------------------------------(3)

$df_{A.mom} = 4\pi\rho V^2(1-a)a.r.dr$ --(4)

$dQ_{bl} = 0.5\rho.W^2 C_T.r.C.B.dr)$ --(5)

$dF_{A.bl} = 0.5\rho.W^2 C_A.r.C.B.dr$ -- (6)

From Fig. (1) $F_T = L\sin\varphi - D\cos\varphi$ ----------------------------------(7)

And $F_A = L\cos\varphi + D\sin\varphi$ -----------------------------(8)

It can write the last two equations as follows

$$C_T = C_L \sin\varphi - C_D \cos\varphi \quad , \quad C_A = C_L \cos\varphi + C_D \sin\varphi$$

The lift and drag forces are calculated from the lift and drag coefficients, which are derived experimentally as a function of the angle of attack. The aerofoil shapes used in wind turbines have lift and drag coefficient curves similar to the ones presented in Fig.(4). For a horizontal axis turbine using an asymmetrical aerofoil section, the angle of attack is normally in the range (-10^{o} to 24^{o}) and therefore, lift and drag coefficients are not experimentally determined outside this range. (13)

The axial and tangential interference factor (a and a') can be calculated from combine equations (3 & 5) as follow,

$$8\pi V\Omega(1-a)a'r^2 = W^2 C_T C.B \qquad \text{----------} \quad (9)$$

From Fig. (2) Can get.

$$W = \frac{\Omega.r.(1-a')}{\cos\phi} \qquad \text{----------} \quad (10)$$

Where the solidity ratio is

$$\sigma = \frac{B.C}{2\pi.r} \qquad \text{----------} \quad (11)$$

sub equations (10)and (11) in equation (9) can get

$$\frac{a'}{1+a'} = \frac{r\Omega(1+a').C_T\sigma}{4\cos^2\varphi.V(1-a)} \qquad \text{----------} \quad (12)$$

From equation (10) and (12) can get:

$$\frac{a'}{1+a'} = \frac{r\Omega(1+a').C_T\sigma}{4\cos^2\varphi.V(1-a)}.\left(\frac{V(1-a)}{\sin\varphi}\right)/\left(\frac{r\Omega(1+a')}{\cos\varphi}\right) \qquad \text{----------} \quad (13)$$

After simplify can get

$$E = \frac{a'}{1+a'} = \frac{C_T\sigma}{4\sin\varphi\cos\varphi} \qquad \text{----------} \quad (14)$$

.From combine equations (4&6) can get

$$8\pi V^2(1-a)a.r = W^2 C_A C.B \qquad \text{----------} \quad (15)$$

From Fig. (1) can get

$$W = \frac{V(1-a)}{\sin\phi} \qquad \text{----------} \quad (16)$$

Sub equation (16) and (11) in equation (15) can get

$$G = \frac{a}{1+a} = \frac{C_A\sigma}{4\sin^2\varphi} \qquad \text{----------} \quad (17)$$

Then from equation (1) and Fig.(2) can get

$$\cot\varphi = \frac{\lambda(r/R)(1+a')}{1-a} \qquad \text{----------} \quad (18)$$

with considering $\lambda_r = \lambda.\frac{r}{R}$ And $\lambda = \frac{R.\Omega}{V}$

Where the torque coefficient is

$$C_q = \frac{2Q}{\rho A V^2 R} \qquad \text{----------} \quad (19)$$

By integration equation (3) can get

$$C_q = 8\int_0^1 \lambda.a'(1-a)(\frac{r}{R})^2 d(\frac{r}{R}) \qquad \text{----------} \quad (20)$$

Sub. equations (18) and (14) in equation (20) can get

$$C_q = 8\int_0^1 \cot\varphi(1-a)^2 E(\frac{r}{R})^2 d(\frac{r}{R}) \qquad \text{----------} \quad (21)$$

Let the local torque coefficient (m_r)

$$m_r = 4(1-a)^2 E(\frac{r}{R})^2 \cot\varphi \qquad \text{----------} \quad (22)$$

According to Prandtl, the reduction of efficiency which results is given for a wind machine having (B) blades, and the wind rotor is running in the neighborhood of optimal condition the

Prandtal relation follows that $$\eta_b = [1 - \frac{0.93}{B\sqrt{\lambda^2 + 0.445}}]^2 \qquad \text{----------} \quad (23)$$

Then equation (19) becomes is $$C_q = 2\int_0^1 m_r \eta_b d(\frac{r}{R}) \qquad \text{----------} \quad (24)$$

In practice to determine C_q, it can be consider for each station of blade to corresponding radius, and make the angle of attack (α) is vary arbitrarily, for instance, from degree to degree and calculate for each station.

- The relative angle (φ)by adding to the considered angle of attack (α) ,
- the twist angle (β) or ($\varphi = \alpha + \beta$)
- The values of CL and CD as a function of angle of attack. (α)
- The quantities G,E, a , a' from equations (14 and 17)
- The tip speed ratio (λ) from equation (18)
- The local torque coefficient m_r from equation (22)

The different values of the coefficient (C_q) as function of (λ) are obtained by measuring the area situated between the various curves graduated tip speed ratio values, using numerical integration (trapezoidal method). Then the power coefficient C_p is related to (C_q) by the relation. $C_p = C_q . \lambda$ ---------------------------- (25)

COMPUTER PROGRAM

A computer program in visual basic was designed, and blade element and momentum theories are used to get the formulas that used in this program, and because the fast running HAWT has chosen, therefore the blade number has taken between 1 and 4, and the aerofoil section are NACA 4415, hence the experimental data from a catalog of low Reynolds number for (CL -α) and (CD - α) lift and drag coefficient has taken from table (1) and re-draw in Fig (4).

The flowchart as in Fig.(5) explain the strategy of the program process which consist many values of variables represent as slides scroll bar such as rated wind speed , blade number, radius of rotor and design tip speed ratio by change one variable and fixed the others, the program draws the curves for the solidity (σ) chord line(c) and twist angle (β with local radial (r/R) and as a result) we get the curves of performance of wind turbine for that changes in variables , and retry other times for others variables until we get the optimum performance by using numerical integration to compute the area under carve (Cp - λ) and optimum design shape of rotor blade of wind turbine.

RESULT AND DISCUSSION

A simplified method of design and performance analysis of a horizontal axis wind turbine rotor has been carried out using a computer program to determine the optimum geometric parameters for the blade of a wind turbine.

After the presentation of results of computer program, all the parameter design are fixed except one parameter is variable and re-try the same processes on others . In beginning, four curves are studied for several design tip speed ratio λ_d (figs. (6, 7, 8 and 9)) the first of three of them with respect to local radius r/R, the last with respect of tip speed ratio as following.

Fig. (6) represents the relation between chord line of blade and local ratio. The values of chord are taken from fig (6) and re-write in table (2). The chord line decrease with increase of r/R for specific value of λ_d and with λ_d for specific value of r/R. For specific values of local radius. The differences in chord for sequences values of design tip speed ratio is large for low design tip speed ratio values , this difference will reduce with increase of λ_d ,and it become very small for high values of λ_d. At λ_d equal to (3) the chord line increase and reach to maximum value at r/R=0.22, then decrease steeply.

Fig (7) represent the relationship between twist angle (β) and local radius (r/R) for several λ_d , the curve shows the twist angle decrease toward blade's tip and there are large twist in regions of close to blade's root, steep till mid of blade ,after that the twist angle seem stability , the slop of curve increase with increase of λ_d .for specific value of (r/R) , the change of(β) at low λ_d are large than of its value at high λ_d . Table (3) shows twist angle (β) values at root ,mid and tip of blade for several λ_d .

Fig. (8) represent the relationship between solidity (σ) and local radius (r/R) for several λ_d , the curve shows the solidity decrease toward blade's tip and there are large difference of its value in regions of close to blade's root, steep till mid of blade ,after that the solidity seem stability especially for high λ_d , the slop of curve increase with increase of λ_d .for specific value of (r/R) , the change of(σ) at low λ_d are large than of its value at high λ_d.

Fig.(9) represent the relationship between power coefficient (C_p) and (λ) for several λ_d ,at λ_d equal to 3 ,the performance of wind turbine is very low because the area under the curve(C_p-λ) is very small and the turbine will work at (λ) between (2 and 7) only. And by return to figs. (6,7and 8) for λ_d equal to 3, the chord, twist angle solidityand are large. The design at λ_d equal to 3 will be not desired. At λ_d equal to 5 ,the area under the curve (C_p-λ) is very large and turbine will work at wide range of (λ) between (2 to 14), ,and we can determine the specification of wind turbine at this value i.e. (λ_d equal to 5)from figs(6,7 and 8) respectively. this case consider one of optimum designs for wind turbine. At λ_d equal to 7 the wind turbine will work at large range of (λ), the area can be greater than when turbine word at λ equal to 5 , but there are loss of energy of wind turbine at ($\lambda < 7$). At λ_d equal to 9 and 11 there are loss in energy for ($\lambda < 10$) therefore specification of wind turbine at $\lambda_d > 7$ is not desired for NACA 4415.

Now, the parameters designs are fixed such as (B ,V_r and λ_d) with the values of (3,7 ,7) respectively ,and change the rotor radius (r),there is no changes in twist angle (β) and solidity(σ) except chord line.

Fig.(10) represents the relation between chord line and local radius (r/R) for several radii of rotor. The chord line reduces with increase of radial ratio r/R and for specific value of r/R the chord increase with increase of rotor radius. when radius equal to (10) the chord line after mid of blade close to 0.5m .at root of blade , the gap between chord value of 10 and 40 is 3.5m , but at tip of blade its value is 1m.

There are small changes noted through run the program , in power coefficient curve w.r.t tip speed ratio for radius less than (25m),but the rest values of radius that greater than (25m) , the power coefficient is constant.

When change the rated wind speed in computer program with fix the other parameter, noted that, there are no changes in chord, twist angle and solidity and as result there are no change in power coefficient.

The last test, the blade number has changing, and other parameters are fixed. Figs.(11) and (12) represented solidity and power coefficient curves w.r.t. to local radius respectively. In Fig.11, the solidity decreases with increase or radial ratio till the mid of blade after that solidity will be approach to 0.05 the solidity reduce with decrease number of blade

In Fig.(12) the performance of wind turbine when blade number equal to 1 is low and raise when blade number equal to 2 , but it very good for blade equal to 3 and 4. The performance of wind turbine at blade number equal to 4 is best for λ less than 10 compared with performance of wind turbine at when blade number equal to 4.

When program running, the curve chord line and twist angle w.r.t radial rotor are not changes for variant blade number.

CONCLUSION

When the blade number are changes, the chord line and twist angle don’t effect but there are only effect on solidity, and as a result, the performance of wind turbine at blade number equal to 3 and 4, give the optimum state. The turbine with one blade don’t desired because the low performance in it.

When the rotor radius is changes, there are no effect on solidity and twist angle but there is only effect on chord line, and there is no effect on performance and as a result, there is a small effect is noted on power coefficient for radius less than 25m.

When design tip speed ratio is changes, there are effects on chord line, twist angle and solidity and as result there is effect on wind turbine performance, the performance of wind turbine for values of λ_d between (5-7), consider as optimum case for NACA 4415 therefore the specification of wind turbine of these values will give the optimum design.

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Table(1): The experimental data from a catalog of low Reynolds number for lift and drag coefficient (CL -α) and (CD - α) $^{(13)}$.

NACA 4415						
angle of attack α	**Re 1.5E+6**		**Re 2.0E+6**		**Re 3.0E+6**	
	CL	**CD**	**CL**	**CD**	**CL**	**CD**
-7	-0.3	0.0105	-0.33	0.0099		
-6	-0.2	0.0098	-0.23	0.0093	-0.23	0.0091
-5	-0.1	0.0092	-0.12	0.009	-0.12	0.0087
-4	0	0.0089	-0.01	0.0086	-0.02	0.0083
-3	0.1	0.0088	0.09	0.0083	0.09	0.008
-2	0.21	0.0088	0.2	0.0082	0.2	0.008
-1	0.31	0.0087	0.31	0.0082	0.3	0.008
0	0.41	0.0087	0.42	0.0082	0.41	0.008
1	0.51	0.0087	0.52	0.0083	0.52	0.008
2	0.61	0.0088	0.63	0.0083	0.62	0.0081
3	0.71	0.0087	0.73	0.0083	0.72	0.0082
4	0.8	0.0086	0.82	0.0083	0.82	0.0083
5	0.9	0.0088	0.92	0.0086	0.92	0.0085
6	0.98	0.0094	1	0.0091	1.01	0.009
7	1.06	0.0102	1.07	0.0099	1.1	0.01
8	1.13	0.0114	1.14	0.0111	1.17	0.0114
9	1.19	0.0133	1.2	0.013	1.24	0.0131
10	1.24	0.0156	1.26	0.0155	1.3	0.015
11	1.29		1.32	0.0178	1.37	0.0167
12	1.33		1.37	0.0199	1.42	
13	1.37		1.41		1.46	
14	1.41		1.45		1.48	
15	1.42		1.46		1.48	
16	1.4		1.45		1.45	
17	1.38		1.43		1.44	
18	1.35		1.41		1.42	
19	1.34		1.39		1.41	
20	1.34		1.39		1.41	
21			1.4		1.41	
22			1.4		1.41	
23			1.4		1.42	
24					1.44	

Table (2):represents the chord along the blade for several λ_d . .

design tip speed ratio λ_d	Chord along the blade (m)		
	at root	at mid	at tip
3	4	5.4	2.6
5	3	3.2	1
7	2.5	2.3	0.6
9	1.8	1.8	0.3
11	1.4	1.4	0.2

Table(3): Represent twist angle (β) at root, mid and tip of for several λ_d .

design tip speed ratio λ_d	**Twist angles along the blade (degree)**		
	root	**mid**	**tip**
3	39	17	11
5	33	8	6
7	26	5	4
9	22	2	3
11	18	1	2

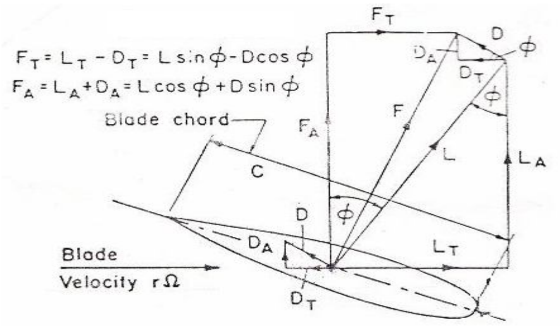

Fig.(1): Force diagram .

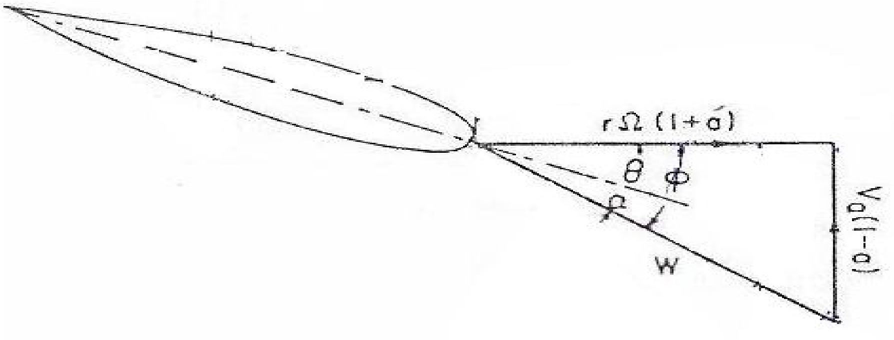

Fig.(2): Velocity diagram .

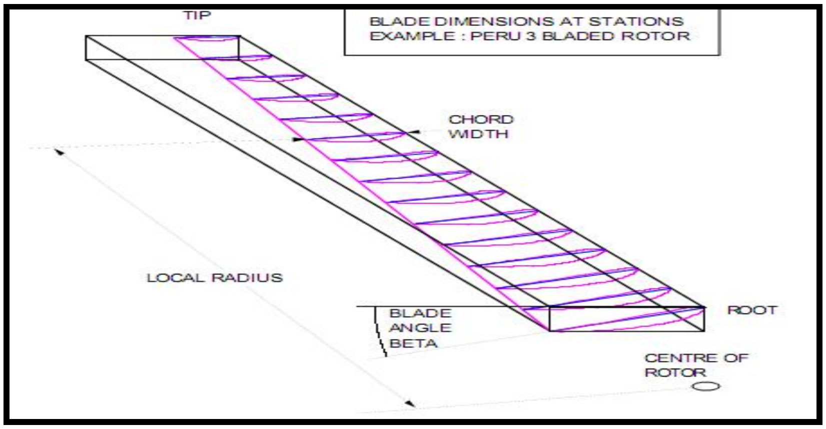

Fig (3): Blade dimension at stations (7) .

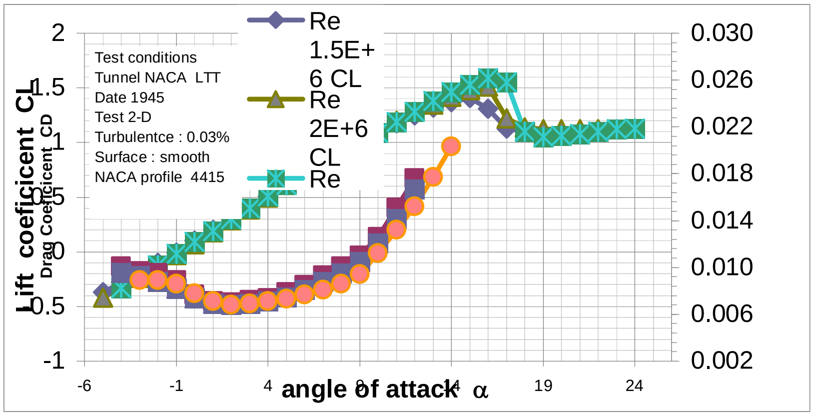

Fig.(4): Lift and drag coefficient as a faction to angle of attack (13) .

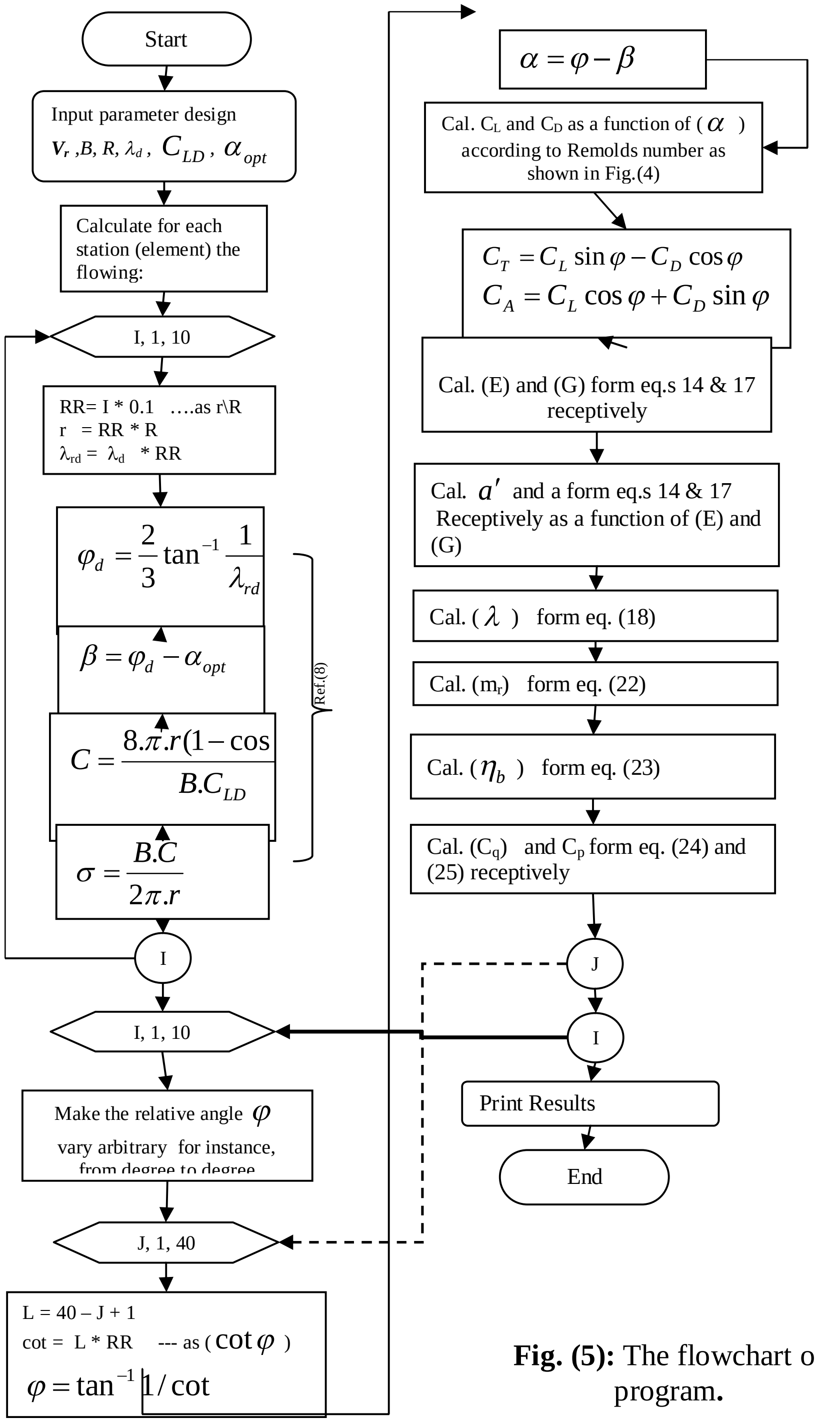

Fig. (5): The flowchart of program**.**

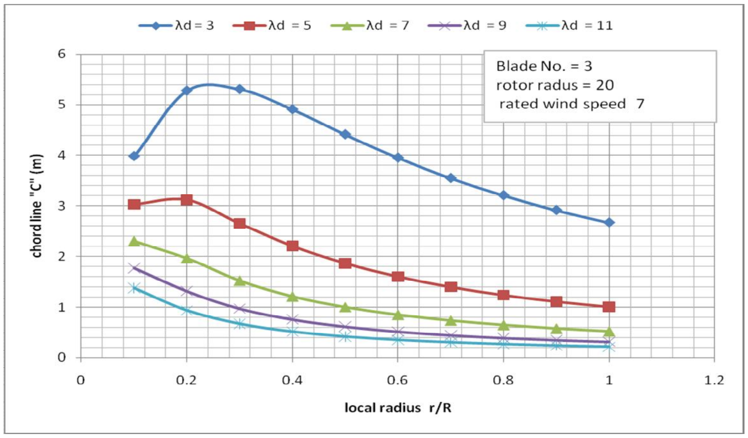

Fig.(6): The relation between Chord line and radial ratio for several design tip speed ratio.

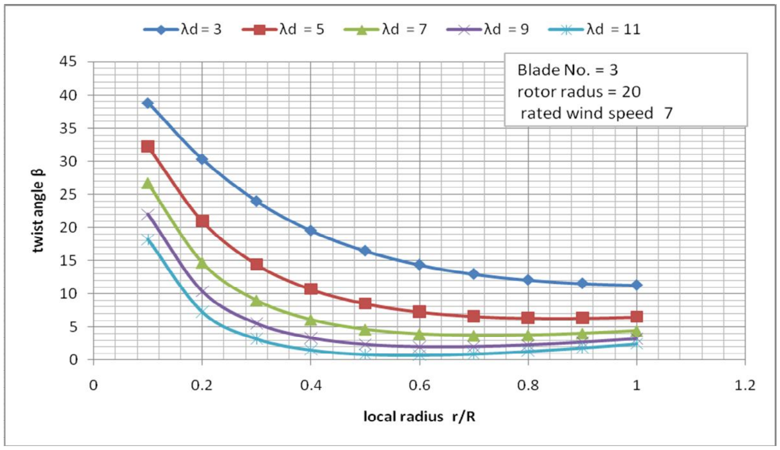

Fig. (7): The relation between twist angle and radial ratio for several design tip speed ratio.

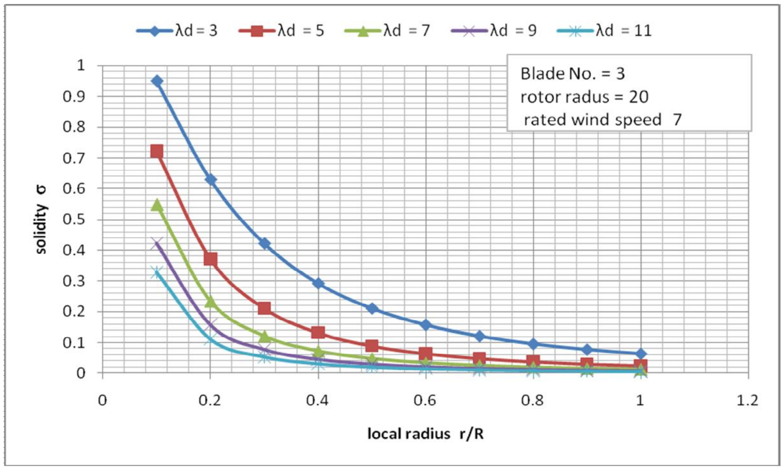

Fig.(8): The relation between solidity and radial ratio for several design tip speed ratio and blade No. equal to 3.

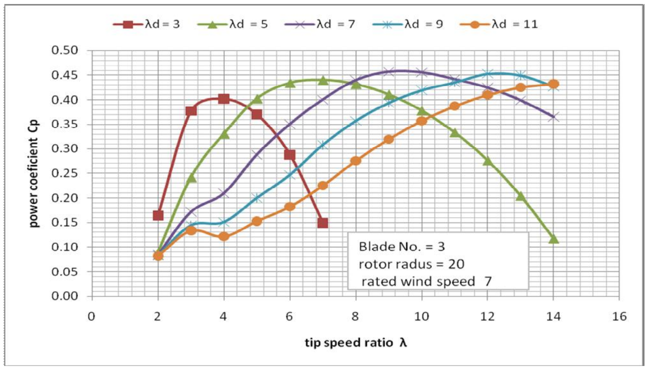

Fig.(9): The relation between power Coefficient and tip speed ratio for several design tip speed ratio and blade No. equal to 3.

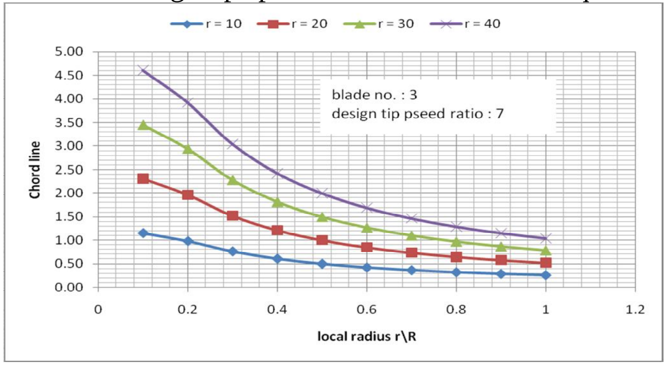

Fig.(10): The relation between chord line and radial ratio for several radii of rotor**.**

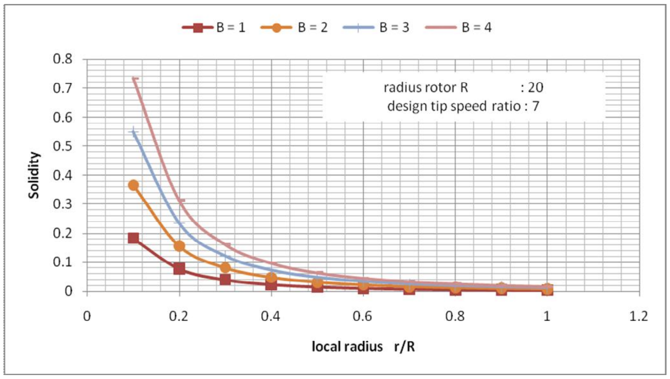

Fig.(11): The relation between solidity and radial ratio for different number of blades.

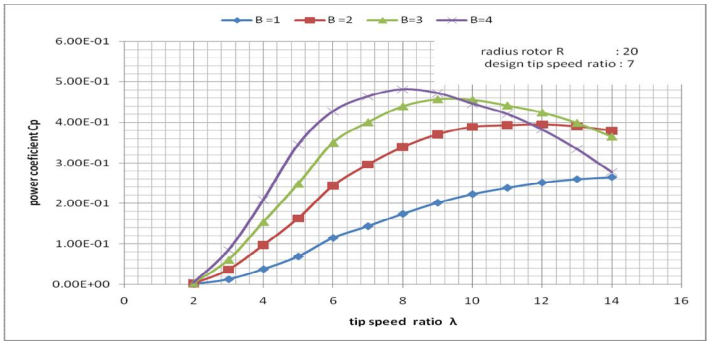

Fig.(12): The relation between power Coefficient and tip speed ratio for different number of blades.

برنامج حاسوبي للتنبؤ بأداء التوربين الهوائي افقي المحور سريع الحركة للوصول الى التصميم الامثل

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قسم الهندسة الميكانيكية – جامعة ديالى

الخلاصة

لقد تم تصميم برنامج حاسوبي بالفجوال بيسك للتنبؤ باداء التوربين الهوائي افقي المحور سريع الحركة لتوليد الطاقة الكهربائية باستخدام نظرية عنصر الريشة ونظرية الزخم . و تم اختيار NACA 4415 للمقطع الانسيابي للريشة . كما تم تمثيل متغيرات التصميم (نسبة سرعة طرف الريشة التصميمية ، نصف قطر الدوار و عدد الريش) على هيئة منزلقات صممت بالفجوال بيسك ، وبتغيير تلك المتغيرات ، فان منحنيات الصلابة ، وتر الريشة وزاوية التواء الريشة على طول الريشة بالاضافة الى منحني اداء الدوار (علاقة معامل القدرة مع نسبة سرعة الريشة) سوف يتم رسمها بصورة لحظية.

لقد تم استخدام التكامل العددي (طريقة شبه المنحرف) لحساب المساحة تحت منحني اداء الدوار، وسوف يسجل البرنامج قيمة تلك المساحة ، وبتغيير متغيرات التصميم ،وبمعرفة اعلى قيمة للمساحة ، سنتعرف على التصميم الامثل لدوار التوربين .

تم التوصل الى ان الدوار ذو الثلاث او الاربع ريش مع قيم نسب سرعة طرف الريشة التصميمية بين (5 - 9) يعطي افضل اداء للتوربين .كما ان تأثير تغير نصف قطر الدوار على اداء التوربين جدا صغير , ولايوجد تأثير ملاحظ بالنسبة الى معدل سرعة الرياح على اداءه عند تغير متغيرات التصميم في البرنامج الحاسوبي.