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Optimum performance of rotor blade with different airfoil for Primus Wind power AIR 40 Wind Turbine 12VDC

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ABSTRACT

The increasing price of fossil derivatives, global warming and energy market instabilities are a major problem. In recent years, these problems led to an increasing using of renewable energy sources such as wind energy. Wind turbine used to extract this energy from the wind to produce power or electricity. Due to low cost, easy for maintenance and it is, portability the most commonly used among wind turbines is small axis wind turbine. Analysis to optimization power coefficient (C_P) of a small wind turbine blade design model (Primus Wind power AIR 40 Wind Turbine 12VDC) are evaluated and discussed in this study. A shape of blade wind turbine is the primery parapeter affected the power output of wind turbine. In this type of turbine NACA2411 used as the blade airfoil as represent shape of blade. For this goal, 185 different airfoils selected. For this purpose, using the XFOIL software to simulate the properties of each airfoil at Re ($1.0*10^5$, $1.5*10^5$, $2.0*10^5$, $2.5*10^5$, $3.0*10^5$ and $3.5*10^5$) and angle of attack from 0° to 10°, Then elimination criteria was performed for removing those airfoils would not suitable for the purpose up on their effiency. At the end of analysing Matlab software used for calculate the power coefficient and selecting the best airfoils design for used manufacture anew blade for that type of small wind turbine with better power coefficient. The output of XFOIL and matlab software showed by tabulates and graphs. As a results show 3 airfoils were selected due to their performance better than other airfoils from an initial group of 185 as exemplification of the methodology namely S1210,SD7034 and S2091, The maximum (C_P) that has been achieved by which used airfoil S1210 equal to 0.52 at Re 350000.

1. Introduction

Using wind turbine for produce a pure energy that extracts this energy in movable wind is becoming more attractive energy source partly due to demand increasing and environmental problems. Normally wind turbine converts the kinetic energy in the wind to mechanical energy, then this mechanical power change to electricity by generator. In this context, aerodynamic characteristics of horizontal axis wind turbines (HAWTs) are very important tools in turbine performance monitoring, turbine control and power forecasting. Empirical and numerical approaches have been employed to evaluate aerodynamic performance of small HAWT , results of this study is Horizontal axis wind turbine working at maximum power coefficient continuously [1]. Aerodynamic optimization has widely become a problem of considerable interest to determine the geometry of an aerodynamic configuration amidst positive design constraints, The purpose of optimizing is to maximize the aerodynamic efficiency at a single layout wind speed .[2] An optimization proposed by combining genetic algorithms with the blade thing momentum theory, which represents the wind simulations and present wind turbine principles discovered in Brazil. A variable velocity pitch-controlled 2.5 MW direct-drive synchronous generator turbine with a rotor diameter of 120 m

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was chosen as concept. Detailed evaluation of the first-rate compromise blade sketch showed that the output of the graph methodology is feasible for manufacturing.[3]The wind blades are regarded as the most necessary and expensive section in the wind system. Therefore, it is necessary to have an in-depth understanding of the behavior of turbine blades. In this research paper, important points has been presented to analyze and optimize the conduct and performance of the blade of the small horizontal axis wind turbine by using Qblade oftware and ten different sections of SG6043 airfoil 1.17 m blade length have been used. The paper exhibits the critical steps to build and optimize the blade of wind turbine, in addition to the aspects and benefits of the software. [4]The blade element principle used to discover the optimum value analytically. The impact of energy coefficient for oblique blade angle, tip velocity ratio, ratio of coefficient of drag and coefficient of elevate, blade solidity introduced, and the optimized set value obtained. [5] Design and optimization of airfoils and a 20 kW wind turbine using multi-objective genetic algorithm and HARP_Opt code.[6] presented the design of three-blade wind turbine rotor which maximized the mechanical power coefficient (C_P) at the operating conditions. The model developed using an actuator disc and validated using both a free-wake lifting line method and three-dimensional Navier-Stokes Solver. The study reported $C_P = 0.51$ and pointed out that it increases and decreases towards the root and tip, respectively.[7] designed a winglet on National Renewable Energy Laboratory (NREL) rotor blade and optimized the computational cost using the artificial neural network at different wind speeds. The study reported around 9% increase in the power for the horizontal axis wind turbine. Winglets are vertical projections on an airfoil blade that help reduce the drag and increase L/D ratio.

Aim of this paper, is to simulate and selection the suitable airfoil to optimize the C_p of this type of small axis wind turbine available in laboratory (Primus Wind power AIR 40 Wind Turbine 12VDC) at Re ($1.0*10^5$, $1.5*10^5$, $2.0*10^5$, $2.5*10^5$, $3.0*10^5$ and $3.5*10^5$) and angle of attack from 0˚ to 10˚,, to achive this goal use the XFOIL and matlab software also elimination criteria was established.

2. Methods and Mathematical Formulation

2.1 System description

This study uses a SHAWT system designed to operate at the Reynolds number, henceforth called (Re), at low wind velocity, which means at laminar flow Re ($1.0*10^5$, $1.5*10^5$, $2.0*10^5$, $2.5*10^5$, $3.0*10^5$ and $3.5*10^5$) and angle of attack from 0˚ to 10˚.These operating conditions were used as constraints in the optimization process. Therefore, all obtained results based on the aforementioned parameters.

The current study used (Primus Wind power AIR 40 Wind Turbine 12VDC) as a wind turbine model to evaluate and optimize the performance. This wind turbine is a SHAWT, although certified under IEC (International Electro technical Commission) requirements applied to the temperature range 14º F (-10º C) to 104º F (40º C). AIR 40 is CSA (Canadian Standards Association) certified.Figure 1. Moreover, Table 1 showed all specification of this type of turbine.

Figure 1. Primus Wind power AIR 40 Wind Tur bine 12VDC

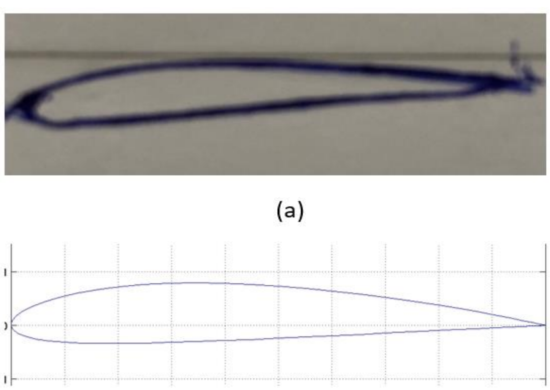
Table 3-1 Parameters of SHAWT [8, 9]

Technical Specifications	
Model	AIR 40
Weight	13 lb / 6 kg
Rotor Diameter	46 in / 1.17 m
Start Up Wind Speed	7 mph / 3.1 m/s
Kilowatt Hours/month	38 kWh/month @ 12 mph / 5.4 m/s avg. wind speed
Maximum Wind Speed	110 mph
Rated Power	160 watts @ 28 mph / 12.5 m/s wind speed

Operating Temperature Range	AIR Breeze and AIR 40 are certified under IEC requirements applying to the temperature range 14º F (-10º C) to 104º F (40º C). AIR 40 is CSA certified

2.2 Simulation and Airfoil selection

To generate more lift than drag, the airfoil used for this purpose was an airfoil of streamlined shape. Flat plate blade can generate lift, but not as much as curved airfoil types, and with somewhat higher drag. To find the properties of any airfoil used in this present work, The Group of Applied Aerodynamics of the department of Aerospace Engineering at the University of Illinois in Urbana Champaign (UIUC) [3], and the National Renewable Energy Laboratory USA (NREL) [4] used as base reference for this process. First, the original airfoil used in this SHAWT model (Prime air 40) must be determined. For this purpose, freehand sketch technique proposed to draw the shape of airfoil, which took on the shape of NACA2411 airfoil as shown in Figure 3.3.



(a)

(b)

Figure 2. freehand sketch result (a) Shape of NACA2411 airfoil (b) airfoil NACA2411 [10].

185 airfoils were selected from both (UIUC, NREL), in which content was useful at low (Re), and different rotor diameter. Because of these experiences, airfoil selection criteria and the designs for wind turbine airfoils and blades have had to change to achieve high and reliable performance. Working specifically for HAWTs, wind energy engineers have been using a new airfoil design. Eppler and Somers (1980) developed one of the most used codes in wind energy engineering. Others were XFOIL and RFOIL (see Timmer and van Rooij, 2003) and PROFOIL (Selig and Tangler, 1995). To optimize the properties of boundary layer and airfoil shape these codes support this idea. Thus, ISES (A two Dimensional Viscous Aerodynamic and Analysis Code) [11] was working with Re less than 500000 as used in this paper. For the current study, several methodologies for airfoil simulation were available for use. The most efficient simulation method used in this paper was XFOIL software developed by Drela [12]. Whatever Xfoil is that software used to design and analysis 0f subsonic airfoils.This algorithm employed in this study to find the characteristics of any airfoils that used. During analysis by XFOIL software, three parameters considered as constant, which are Re, Mach number and "Ncrit" (n) number. Value of Re was determined as $1.0x10^5$, $1.5x10^5$, $2.0\ x10^5$, $2.5x10^5$, $3.0x10^5$ and $3.5x10^5$. Due to wind speed, the value of Mach number did not exceed 0.2. XFOIL software allows to use Mach number as input and the value must be less than 0.3; outside of this range, results of any simulation become 0 as tested by Mauclere X. [13]. To estimate the maximum value of (C_l), the angle of attack α was independent value between 0 to 10. For decreasing errors and to obtain results at any number, this simulation used 103-cycle iteration. The value of Cl and Cd would be taken from output of XFOIL simulation as showen in figure 1, which is appeared the results of NACA2411 at Re equal to $1.0x10^5$.

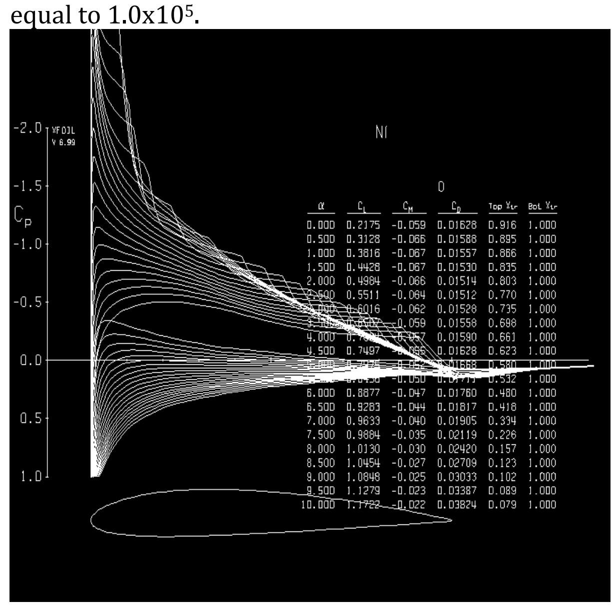


Figure 3. XFOIL Results of NACA2411 Airfoil at Re 100000

The elimination criteria occurred over more than three rounds to eliminate the airfoils. Any round of this procedure upon the main purpose parameter was the Glide Ratio (GR), the higher GR of airfoils were remained others airfoils which has lower GR eliminated from the process. In addition, some airfoils eliminated due to (invalid compressibility correction factor) message as shown by XFOIL software.

2.3 **Matmatical model for calculation of C_P**

The output power of wind turbine has determined by several parameters. Among them are turbine speed, rotor blade rotate, size and shape of turbine, rotor geometry, whether it is a HAWT or a VAWT, and wind speed. The maximum achieved power coefficient for turbines calculated by used matlab software and shows the results by graphs. With an optimum blade shape but a finite number of blades and aerodynamic drag has been calculated by Wilson et al 1976 [14] their fit to the data is accurate to within 0.5% for tip speed ratios from 4 to 20, lift to drag ratios ($\frac{C_l}{C_d}$) from 25 to infinity, and from one to three blades (B):

$$C_p = \left(\frac{16}{27}\right)\lambda\left[\lambda + \frac{1.32 + \left(\frac{\lambda-8}{20}\right)^2}{B^{\frac{2}{3}}}\right]^{-1} - \frac{0.57(\lambda^2)}{\frac{C_l}{C_d}\left(\lambda + \frac{1}{2B}\right)}$$

Since, C_p (power coefficient of wind turbine) depend some parameters that used in design of wind turbine that appear in above equation, like λ Tip speed ratio=7 which is most useful for low Reynolds number , $\frac{C_l}{C_d}$ its ratio of between two-dimensional lift coefficient $C_l$and two-dimensional drag coefficient C_d when taken from the output of XFOIL software, and B which represent number of blades. Power coefficient for wind turbines blade calculated by used matlab software and showed the results by graphs with all other data and results of XFOIL software.

3. Results

At the first step of simulation 28 airfoils deleted due to have errors codes in XFOIL simulation, because compressibility correction factors were invalid, this is beacause the geometry of airfoil became sharp at the leading eadge, shape of airfoil define by connection coordinates points, Also this error make the upper and lower of airfoil cross over on the trealing edge. Then at a reference of evaluate Glide Ratio at each value of Re, Airfoil with GR value under the mean value, Deleted from processes, So at Re $1.0x10^5$, $1.5x10^5$ and $2\ x10^5$ eliminated 35 airfoils at each stages, at $2.5x10^5$, $3.5x10^5$ 82 airfoils eliminated, using the highest mean value of GR, 24 airfoils eliminated. At the end, 16 airfoils deleted because the value of GR decreased more than 10% due to change of in a range 0.5 grades of angel of attack.

Finally, 5 airfoils and original one used to simulation analysis processes for find the value of coefficient of performance in matlab software.

Figure 4, 5,6,7,8 and 9 arranges in a table the variation of the performance coefficient as a function of Re of each airfoil and presented the maximum value of (C_P). Figure 4, 5,6,7,8 and 9 gave the moment information of the most high rotor performance coefficient and ideal angle of attack at each Standard Airfoils, were S1210, S2091 and SD7034 selected the best airfoil aerodynamics for small wind turbine, and better than the orginal one that used for our HAWT which is NACA2411. Where, S1210 Fig. 4, Fig. 7, the S2091 Fig. 5, Fig. 8 and SD7034 Fig. 6, Fig. 9.

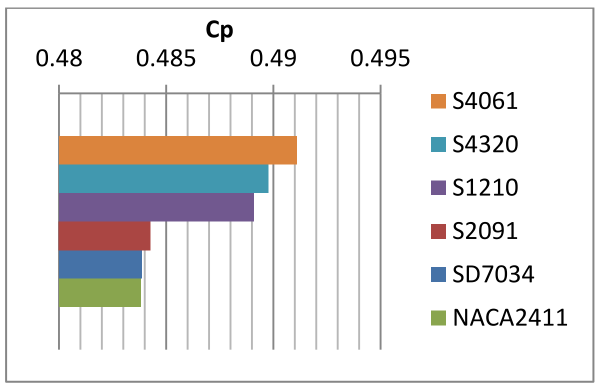


Figure 4. Value of max-C_P for selected airfoils at Re 100000

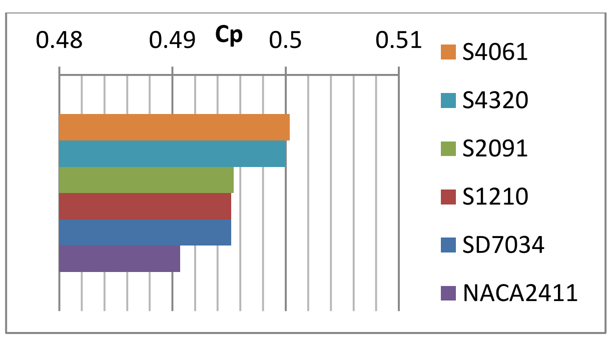


Figure 5. Value of max-C_P for selected airfoils at Re 150000

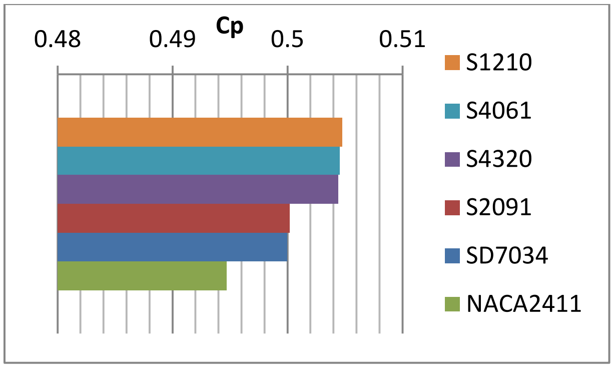


Figure 6. Value of Max-C_P for selected airfoils at Re 200000

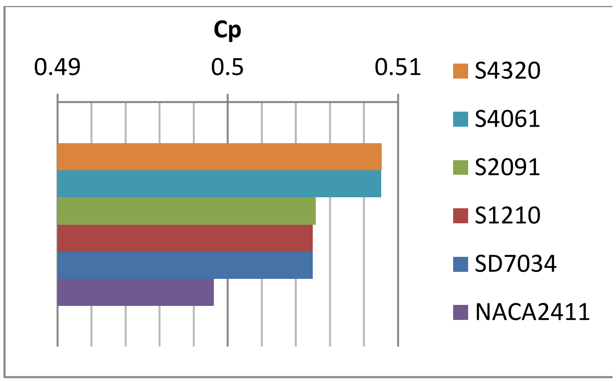


Figure 7. Value of max-C_P for selected airfoils at Re 250000

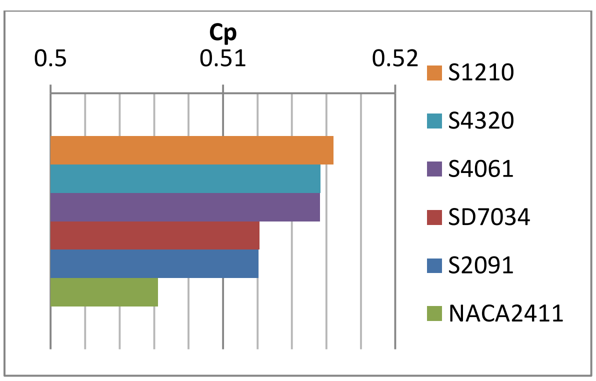


Figure 8. Value of max-C_P for selected airfoils at Re 300000

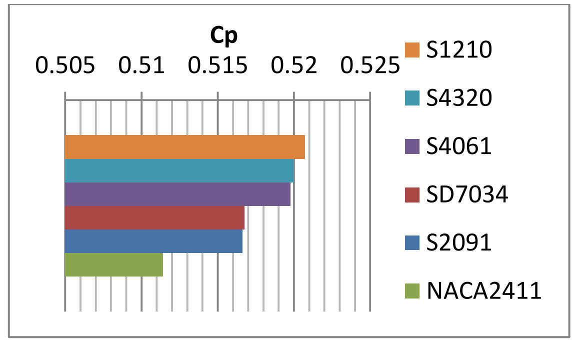


Figure 9. Value of max-C_P for selected airfoils at Re 350000

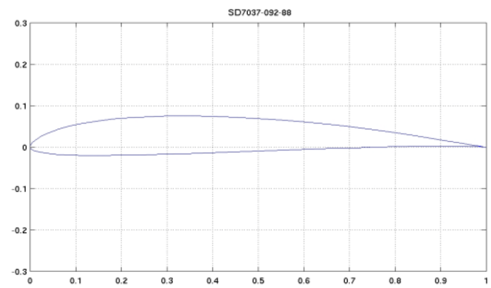


Figure 10. SD7037Airfoil.

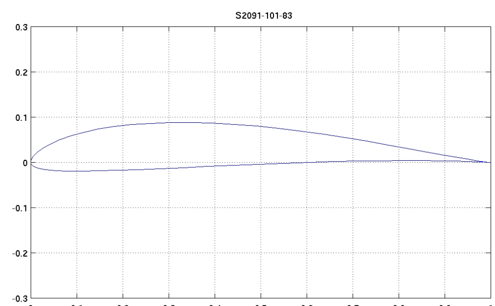


Figure 11. S2091 Airfoil.

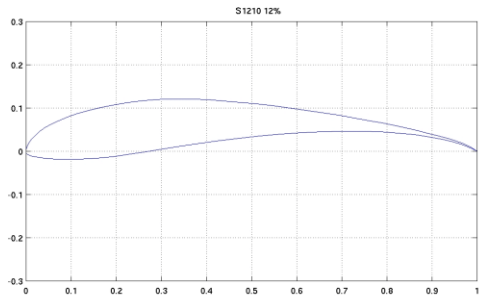


Figure 12. S1210 Airfoil.

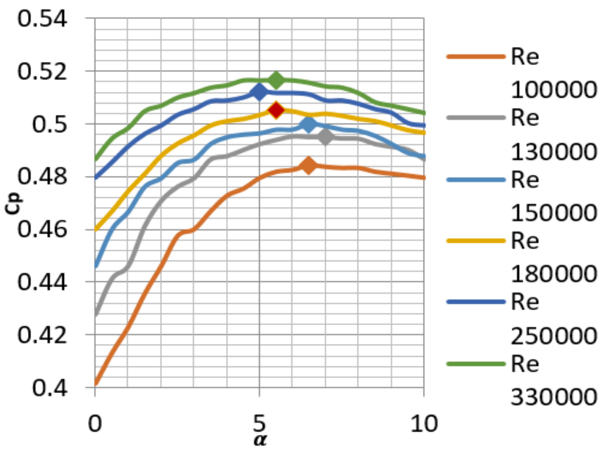


Figure 13. Matlab results of S2091 Airfoil

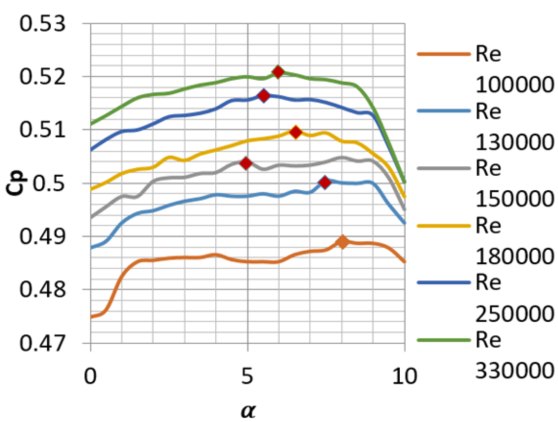


Figure 14. Matlab results of S1210 Airfoil

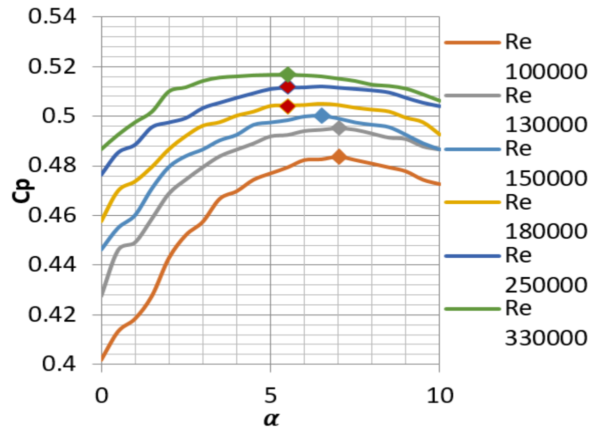


Figure 15. Matlab results of SD7034 Airfoil

4. Dicussion

In any step of simulation procedure discarded some airfoils with different reason at each step, First step due to conflict in the step of calculation of the aerodynamic coefficient some airfoils were deleted. For the second step of the simulation procedure expected value was used for removing those airfoils were not suitable for this work. About 12 airfoils deleted upon their GR at Re 100000 lower than average value, Also more than 22 airfoils discarded because at Re 330000 their GR below the average value and 77 airfoils were removed due to the differential value of α from Re 100000 to 330000 was more than 2, these would not guarantee the wind turbine generation would stable. In the present work the parameter α used in range 0 to 10 because all selected airfoils were curved shape, which wind turbine begins producing lift coefficient from 0 to 10 and from 10 to more separation of boundary layer and slump was happened in wind turbine. In other side the value of α more than 10 is more suitable for those airfoils which they have a symmetric shape as evaluated by Burton, T., Jenkins [15]. Although in some commercial industry of wind turbine used pitch control that used to adjust angle of blade for remaining the power output of wind turbine in maximum value. Lastly, 6 airfoils remained which one of them was original airfoil (NACA2411) that was used in this type of wind turbine, after used Matlab software to analyses the performance coefficient, the results of those airfoils evaluated and tabulated in figure 1 to 6, Variation of the performance coefficient is presented at each Re value for last 6 airfoils. Finally 3 airfoils had lower (C_P) than the others as shown in figure 1 to 6, that's why the airfoils S1210, S2091 and SD7034 were choose as the best airfoil performance for the present work. The coefficient performance as the percent of α

at each (Re) presented in figure 7 for S2091, figure 8 for S1210 and figure 9 for SD7034. In addition, they had a good range of changing the value of α which more suitable making application of wind turbine by those types of airfoils. Any change in α +-0.5 degree tend to cahnge the C_P lower than 10%.

5. Conclusion

A small wind energy portable turbine (SWEPT) operated using kinetic energy and known for its silent operation, portability and low maintenance cost. In the present paper, a unique methodology of analyzing power coefficient developed to select the optimal airfoil in small wind turbine available in laberetory (Primus Wind power AIR 40 Wind Turbine 12VDC). This was carried out by analyzing and using the simulation of XFOIL software to reduce mathematical attitude analysis, and used Matlab software for analysis the (C_P) of any airfoil selected at each value of Re, which allowed easiest way to plot the performance of airfoils, conception, and performance analyzing by graphically for small wind turbine. Although, by this method achieved 3 suitable samples to optimization the performance of small wind turbine, At a low speed of wind and production of wind small turbine, Depend up on figure 4, 5,6,7,8 and 9.The results showed that, With the use of airfoils S1210,SD7034 and S2091 in small wind turbine the coefficient of performance was increased The maximum (C_P) that has been achieved by which used airfoil S1210 equal to 0.52 at Re equal to 350000. In the otherhand the maximum, (C_P) for original airfoil used in wind turbine equal to 0.51 at Re equal to 350000.Although in the future work the selected airfoils, mechanical strength and manufacturing process are the following research projects in order to use them in experimentaly test on the (AIR 40 Wind Turbine 12VDC).

6. Nomenlecture

α Angle of attack

C_l Two-dimensional lift coefficient re spect tive-ly

C_d Two-dimensional drag coefficient

C_p Power coefficient of wind turbine

λ Tip speed ratio

$\frac{C_l}{C_d}$ Ratio of between lift and drag coefficient

B Number of blades

c Airfoil chord length of the blade

l Length of a blade element, in m

D Rotor diameter, in m

P Rotor Power, in W

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