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Mini Scale Horizontal Axis Wind Turbine Blade with Different Mixed Airfoil and their Performance in QBLADE

[1]R. Gayathri, [2] D. Ponmary Pushpa Latha, [3]S. Thanga Helina, [4]Rajib Kanti Mondal [5]Nadar Glorintha Jeeva

[1]Department of Aerospace, Karunya University, Tamilnadu, India

[2]Department of Digital Sciences, Karunya University, Tamilnadu, India

[3]Department of Commerce, Karunya University, Tamilnadu, India

[4]Department of Aerospace, Karunya University, Tamilnadu, India

[5]Department of Aerospace, Karunya University, Tamilnadu, India

Abstract. Wind energy is a clean, renewable energy source, and controlling green wind energy is a key driver of sustainable growth and development. This energy can be taken advantage of wind turbines. This paper is based on the Blade-Element-Momentum (BEM) analysis. BEM was developed using the Q-Blade v0.96, which is a free software to predict the performance of wind turbine. The main objectives of this article are to find the power, torque and power factor of small-scale horizontal-axis wind turbine blades.

Keywords— QBLADE, HAWT, Blade Element Momentum, Power, Torque.

1 Introduction

Solar energy is a type of wind energy and it is a leading provider of renewable energy. Electrical energy or power is produced by wind energy through some processes. In the wind turbine, Mechanical power is formed from kinetic energy. The opposite energy conversion can be attained using generator. Wind power is the use of air streams in wind turbines mechanical generators for electrical power. Wind energy, as an alternative to the combustion of fossil fuels can able to form with nil greenhouse gas emissions during the operations and it uses no water and less land.Net environmental impacts are much less of a problem than for non-renewable energy sources.

2 Airfoil Selection

Thick aerodynamic profiles used at the tip of the blade to provide adequate and thin strength at the tip to improve aerodynamic performance.

Blade1 : Root: SG6040, Tip:SG6043

Blade 2: Root: S823, Tip: S822

Blade 3: Root: NACA 4412,

Tip: NACA 2412.

Table 1: Details of Performance Parameters

AIRFOIL NAME	CL	CD	L/D max	Max angle of attack
SG6040	1.222	0.024	50.8	9
SG6043	1.379	0.021	65.8	7
S822	1.162	0.028	41.6	8.5
S823	0.930	0.022	42.5	9.5
NACA 4412	1.351	0.024	55.3	9
NACA2412	0.975	0.019	50.06	7

3 Blade Element Momentum Method

Axial induction factor, $\mathbf{a = V_1 - V_2/V_1}$

Axial force,

$\mathbf{dFx = (1/2)\ \rho V_1^2[4a(1-a)]\ 2\pi rdr.}$

Moment of Inertia of an annulus, $\mathbf{I = mr^2}$

Angular Moment, $\mathbf{L = I\ \omega}$

Torque, $\mathbf{T = dL/dt}$

Angular induction factor, $\mathbf{a' = \omega/ 2\Omega}$

Tangential force,

$\mathbf{dT = 4a'(1-a)\ \rho V\Omega r^3\pi dr}$

Tip speed ratio, $\mathbf{\lambda r = (\Omega r/ V)}$

Solidity $\mathbf{\sigma' = Bc /2\pi}$

Kinetic energy, $\mathbf{Ek = (1/2)\ mv^2}$

wind power, $\mathbf{p = EK/t}$

Wind power, $\mathbf{P = (1/2)\ \rho Av^3}$

Power coefficient,

Cp =Rotor power/wind power =$\mathbf{P/ ((½)\rho Av^3)}$

Rotor power, $\mathbf{P = (1/2)\ Cp\eta\rho Av^3}$

Power coefficient, $\mathbf{Cp=4a(1-a)^2}$

IV Blade design procedure

In order to derive maximum power, the following steps are followed.

Step-1: Power P = (1/2) $Cp\eta\rho Av^3$

where, P represents Power, C_P is the parameter which denotes power coefficient, η indicates both mechanical and electrical efficiency.

Step-2: Select (λ) as a tip speed ratio for the wind turbaine and the TSR value is either 6 or 7 and it is considered as low wind speed region.

Step-3: The number of blades (B) can be fixed based on the prior experience.

Step-4: Rotor blade is designed by two airfoils, In such a way that, thick profile at the root and thin profile at the tip section.

Step-5: Chord distribution followed by twist distribution in the spanwise direction can be done by optimized **Schmitz theory** as follows,

Q= (inflow angle-angle of attack).

$$Q = \frac{2}{3}\tan^{-1}\frac{1}{\lambda_r} - \alpha_D$$

$$c = \frac{16\pi r}{BC_L}\{\sin(\,{}^{1}/_{3}\tan^{-1}{}^{1}/_{\lambda_r})\}^2$$

4 QBLADE Simulation

The QBlade is a freeware which is used to do the simulation and design of turbine. Blade Element Momentum (BEM) method has been used in QBlade in order to ensure the efficiency of horizontal-axis wind turbines by duplicating the flow. Graphical user interface of QBlade have various features that includes: design of custom airfoils which is used compute airfoil lift-and drag and viscous-inviscid coupled panel method code. In addition, an aerodrome polar extrapolation module, for a 360° AOA range is incorporated that is far away the stall point. Blade assembly was discretized into 14 smaller elements using BEM analysis.

The successful solution convergence in the iterative procedure of BEM results element wise lift and drag coefficients. Number of iterations carried out in this research work was 1000. The researcher can see some in built features like new tip loss, 3D correction etc.,

A) Simulation of SG6040-SG6043 airfoil

First, SG airfoil is imported in QBlade .

The Qblade simulation results of SG6040 airfoil are displayed in fig 2 below. The lift, drag and other performance parameters distributions are mentioned in the plot.

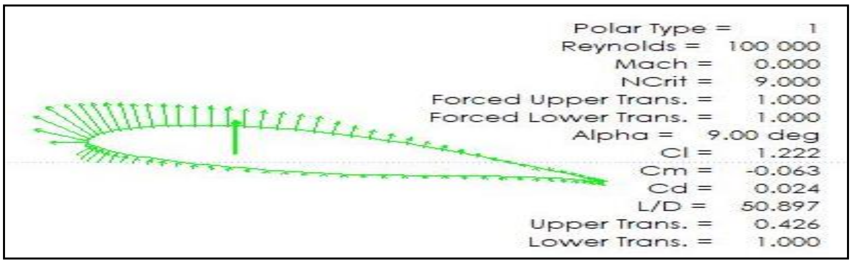

Fig 1: SG6040 Aifoil analysis

Similarly, the Qblade simulation of SG6043 airfoil is also implemented and the outcome is depicted in fig 2 below.

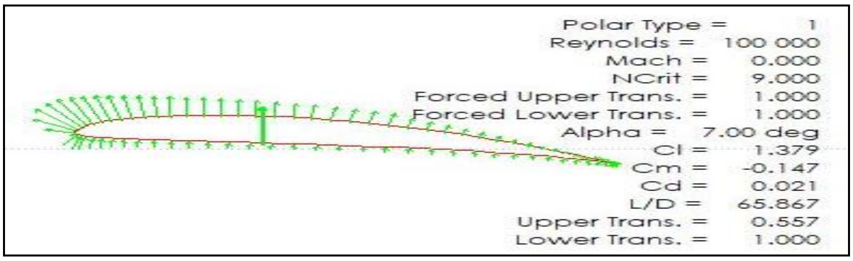

Fig 2: SG6043 Airfoil analysis

Sectionwise airfoil and its twist angle are shown in table 2.

Table 2 Various airfoils and its positions

HAWT

3 blades and 0.20 m hub radius ☑ Blade Root Coordinates

	Pos (m)	Chord (m)	Twist	Foil
1	0	0.05	0	Circular Foil
2	0.05	0.05	0	Circular Foil
3	0.1	0.146327	8.96249	SG6040
4	0.2	0.121895	3.43495	SG6040
5	0.3	0.0835468	1.93142	SG6043
6	0.4	0.0717943	-0.471192	SG6043
7	0.5	0.0627253	-2.2157	SG6043
8	0.6	0.0555836	-3.53768	SG6043
9	0.7	0.049844	-4.57303	SG6043
10	0.8	0.0451454	-5.40536	SG6043
11	0.9	0.0412359	-6.08877	SG6043
12	1	0.0379366	-6.65981	SG6043
13	1.1	0.0351175	-7.14399	SG6043
14	1.2	0.0326826	-7.55967	SG6043

The complete assembly with SG6040 and SG6043 airfoils is shown in fig 4 below.

B) Simulaton of S822- S823 airfoil

S822 airfoil is imported in Qblade software.

The simulation result of S823 and S8222 airfoils are shown in fig 6 and 7 below.

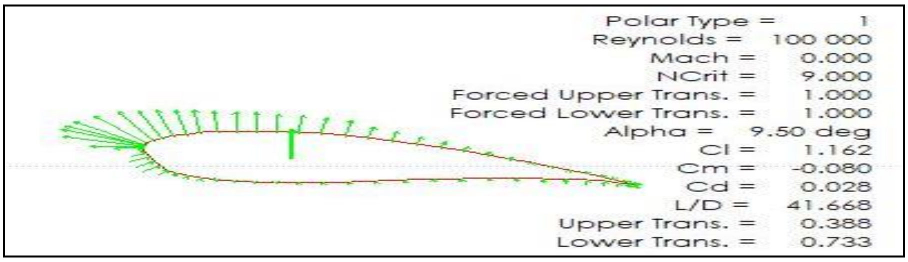

Fig 3: S823 airfoil analysis

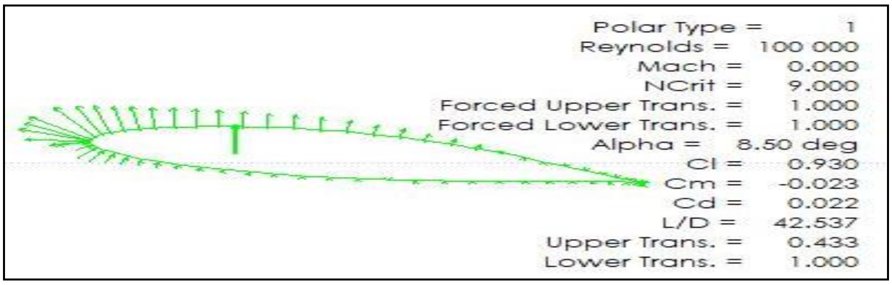

Fig 4: S822 airfoil analysis Sectionwise airfoil and its twist angle are shown in table 3.

Table 3 Various airfoils and its positions

HAWT

3 blades and 0.20 m hub radius ☑ Blade Root Coordinates

	Pos (m)	Chord (m)	Twist	Foil
1	0	0.05	0	Circular Foil
2	0.05	0.05	0	Circular Foil
3	0.1	0.15952	10.4625	S823
4	0.2	0.132886	4.93495	S823
5	0.3	0.122013	1.93142	S822
6	0.4	0.104849	-0.471192	S822
7	0.5	0.0916048	-2.2157	S822
8	0.6	0.081175	-3.53768	S822
9	0.7	0.0727928	-4.57303	S822
10	0.8	0.0659309	-5.40536	S822
11	0.9	0.0602215	-6.08877	S822
12	1	0.0554031	-6.65981	S822
13	1.1	0.0512861	-7.14399	S822
14	1.2	0.0477301	-7.55967	S822

The complete assembly with S823 and S822 airfoils is shown in fig 8 below.

C) Simulation of NACA 4412-NACA 2412

The Qblade simulations are shown in figure 10 and 11.

Fig 5: NACA 2412

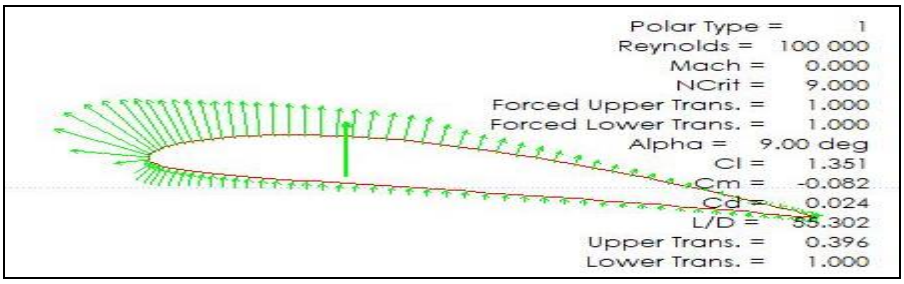

Fig 6: NACA 4412

Table 4 Various airfoils and its positions

HAWT

3 blades and 0.20 m hub radius ☑ Blade Root Coordinates

	Pos (m)	Chord (m)	Twist	Foil
1	0	0.05	0	Circular Foil
2	0.05	0.05	0	Circular Foil
3	0.1	0.135974	8.46249	NACA 4412
4	0.2	0.113272	2.93495	NACA 4412
5	0.3	0.106511	2.93142	NACA 2412
6	0.4	0.0915279	0.528808	NACA 2412
7	0.5	0.0799663	-1.2157	NACA 2412
8	0.6	0.0708615	-2.53768	NACA 2412
9	0.7	0.0635444	-3.57303	NACA 2412
10	0.8	0.0575543	-4.40536	NACA 2412
11	0.9	0.0525702	-5.08877	NACA 2412
12	1	0.048364	-5.65981	NACA 2412
13	1.1	0.0447701	-6.14399	NACA 2412
14	1.2	0.0416659	-6.55967	NACA 2412

5 Result and Discussion:

A. Result from SG6040-SG6043:

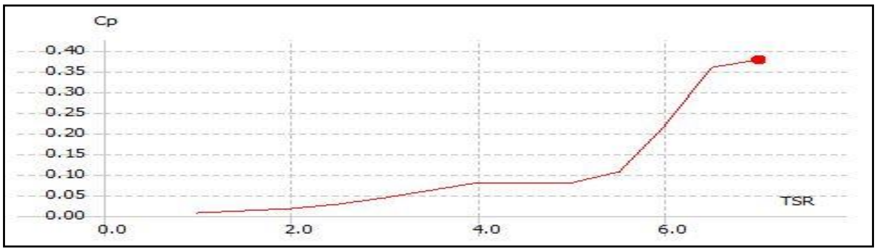

Fig 7: Variation of CP with TSR

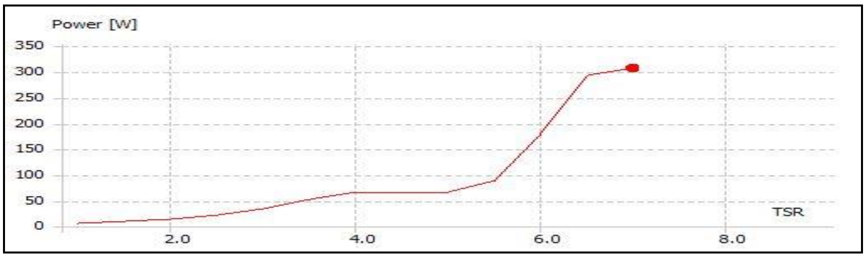

Fig 8: Power vs TSR

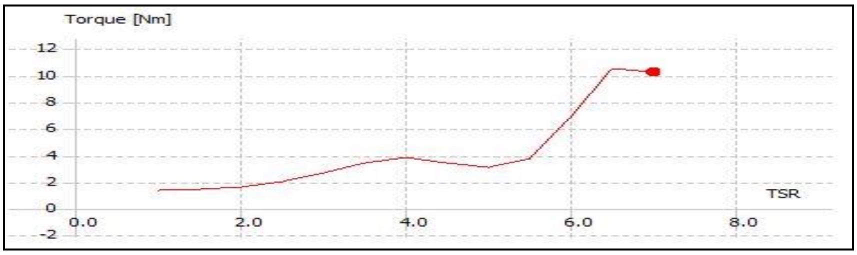

Fig 9: Torque vs TSR

B. ***Result from S823-822:***

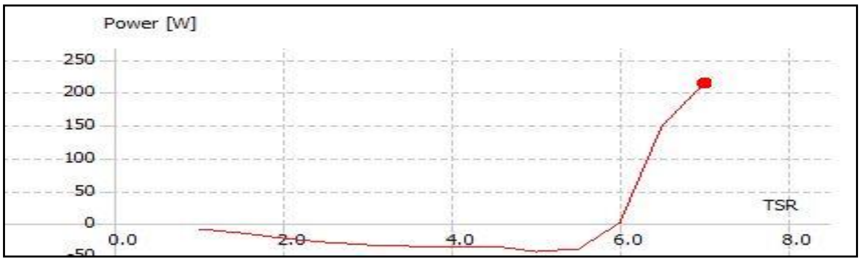

Fig 10: Power vs TSR

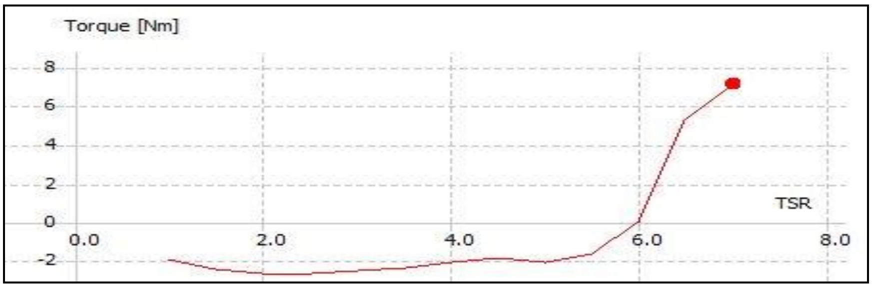

Fig 11: Torque vs TSR

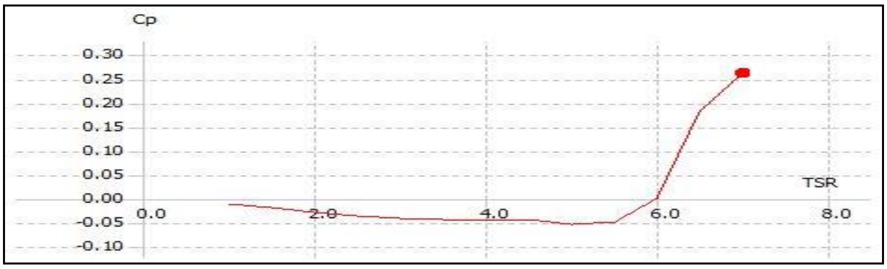

Fig 12: Cp vs TSR

C. ***Result from Naca 4412-Naca 2412:***

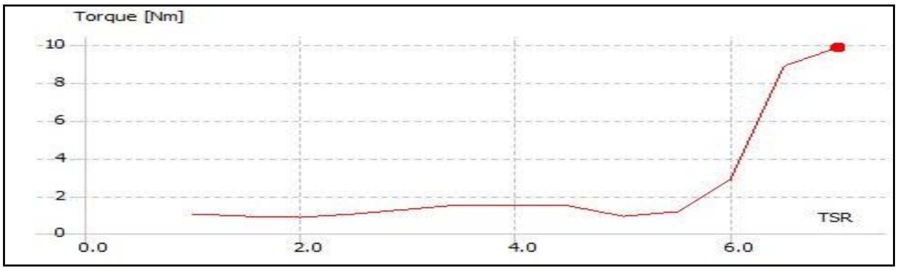

Fig 13: Torque vs TSR

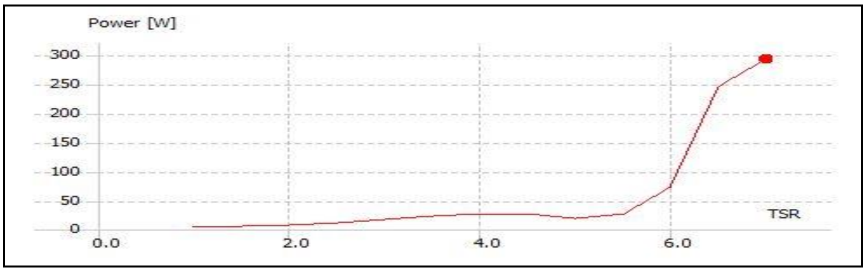

Fig 14: Power vs TSR

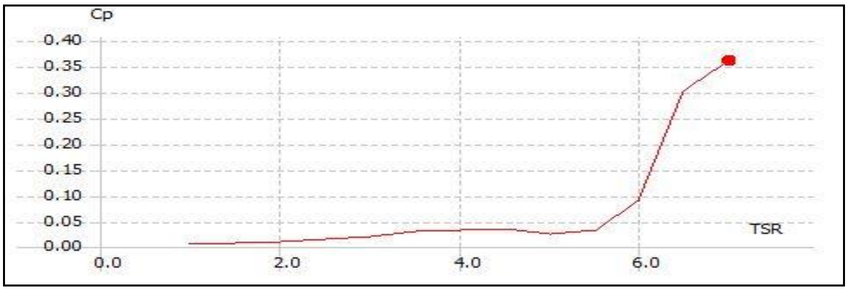

Fig 15: Cp vs TSR

D. Final result and conclusion:

Table 5 Comparison of airfoils

Name of Mixed airfoil	Torque	Power	Power coefficient
SG6040-SG6043	10 Nm	305 W	0.38
S823-S822	7 Nm	210 W	0.27
NACA4412-NACA2412	9 Nm	295 W	0.36

By comparing the results, it is found that SG6040-SG6043 configuration produces the maximum torque and power.

The optimal design with airfoil configuration SG6040-SG6043 has a standard thickness value as 10% and it is considered as maximum. In addition to this, the value of of camber is 5.5 % and the leading-edge radius value is considered as 1.7 %.

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