

Selection of Twist and Chord Distribution of Horizontal Axis Wind Turbine in Low Wind Conditions

M Purusothaman^{1,*}, T N Valarmathi², S Praneeth Reddy³,

¹Assistant Professor, ²Associate Professor ³Student,

Faculty of Mechanical Engineering,

Sathyabama University, Chennai-600119, Tamilnadu, India.

* E-mail address: purusothmani@gmail.com.

Abstract— India has a vast source of renewable energy sector, in that wind energy contributes a major role. The required source of wind energy in India cannot be able to attain maximum generation due to the operation wind turbine under European atmospheric condition. There is a need to optimize blade profiles which should be suited for low wind condition (India) that leads to increase in coefficient of performance. The present works varying of blade profiles taken in root, mid and tip section of blades are evaluated. According to properties of blade element momentum theory (BEMT) and computational work are developed for getting power curves for varying parameters such as tip speed ratio, lift and drag coefficient and main parameters like chord and twist distribution.

1. Introduction

In present scenario the demand for electricity in India has been increasing due to the increase in population and economic development in our country this has lead to a major electricity crisis in our country because a major part of electricity produced in India is by burning fossil fuels such as coal which is exhausted near future. Thermal power plants are the main source of electricity production in India as coal is easily available due to the fact that India has the third largest coal reserves in the world but this leads to a lot of environmental concern as coal is a major source of green house gases which would had lead to depletion of the ozone layer. In order to decrease the effect of environmental degradation and for a cheaper source of fuel India is considering renewable energy such as wind energy. Mankind started using wind power centuries ago with the help of wind mills. Wind mills were used for circulating water for irrigation purposes. The best choice of renewable source of energy is wind energy. There has been a constant increase in deployment of wind energy around the world. The efficiency of the wind turbine depends on various subsystems such as: blades, gearbox, and electric generator.

In wind turbine one of the key elements is blade which is used to converts the kinetic energy into electricity through generators [8]. The design and optimization of the wind turbine forces are evaluated through EEM theory [3]. While designing the blades the main factors are power extraction and starting torque is to be consider [7]. The maximum energy that can be extracted from the wind can be calculated using Betz limit. The Betz limit was found out by Albert Betz which states that no wind turbine could convert more than 59.3% of wind energy is converted into electrical energy. Wind turbines can rotate in horizontal or vertical axis. Horizontal axis wind turbines are ones in which the shafts are located parallel to the ground where as vertical axis wind turbines are ones in which the



shafts are located perpendicular to the ground [6]. Based on the limited knowledge and information investigations started on the HAWT in early 80's, but only limited amount of work had been done in this field. There various classes based on number of blades, wind direction and brake system. This paper concentrates on the three blades Horizontal Axis Wind Turbine. In HAWT the blades are fixed at 120° and rotate about the same direction and the axis of the wind turbine is defined by Z-axis, radially outward from the hub center along the blade axis, X-axis, perpendicular to the blade axis, and in the blade and shaft axis in downward direction and Y-axis, perpendicular to the blade and shaft axis make a right handed co-ordinate system. Turbines of this type are aesthetic and they produce less noise. Hence Wind Turbines of this type are suitable for economical usage. The selection of blade profiles for Indian wind condition is done by carrying literature survey, choose a existing multi section airfoil, calculate the performance using analytical tool for selected airfoil, comparisons of the performance data and optimization of the performance. In this project we are mainly going to concentrate on the twist and chord distribution of the rotor blade.

2. Work Methodology

2.1 Selection of Twist and Chord Distribution

This paper mainly deals with suitable modifications of twist and cord distributions of a wind turbine blade so that it can attain rated power at low wind speed conditions. The design and analysis are carried out by using software called PROPID [4]. It will allow designers to specify peak power for a stall regulated wind turbine. PROPID is a computer program for the design and analysis of horizontal axis wind turbines Inverse design capability is the unique strength of the current design method [6]. The current methods directly specify the peak power for a stall-regulated rotor. The desired peak rotor power is achieved by adjusting the user selected input by using iterative inverse solver.

2.2 Blade Design

The ratio between the speed of the blade tips and the speed of the wind is called tip speed ratio [5]. 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. Use of aluminum and composite materials 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. Schematic representation of chord and twist distribution is represented in figure 1 and the input parameters for propid is listed in table 1.

Table 1. Input Parameters for Propid

Number of blades	3
Radius	30 m
Hub	98 m
Twist and Chord distribution	PROPID
Blade pitch	6°
Tip speed ratio	6
Wind speed	12 m/s

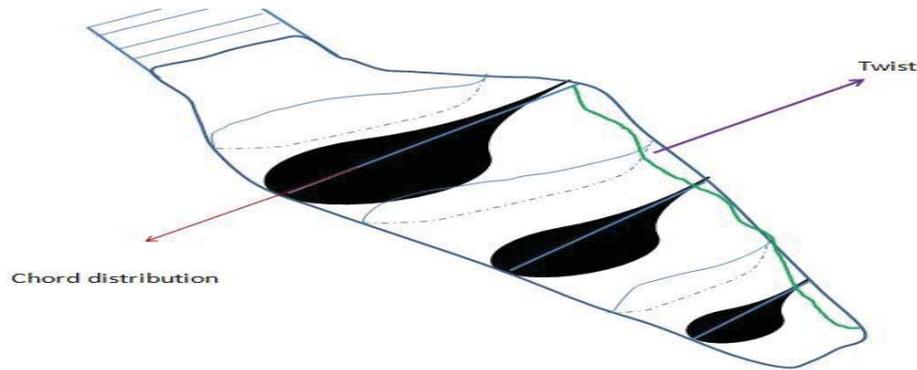


Figure 1. Blade Parameters

2.3 Twist distribution

The twist and chord distribution are altered with the help of a software known as PROPID. This was developed by National Renewable Energy Laboratory. The twist and chord distribution based on the Mat lab genetic toolbox is used as the optimization procedure. Default values are used for most of parameters of the genetic algorithm. To improve the convergence speed the multiple population method is used. Four populations with 50 individual in each are used with co- evolution and migrate for every ten generations. Fraction of the 5% on best individual migrates to other populations [2]. The below table 2 was generated using the above method.

Table 2. Twist distribution with different range

BASE	INC 5 %	10%	15%	20%	25%	DEC 5				
						%	10%	15%	20%	25%
6	6.3	6.6	6.9	7.2	7.5	5.7	5.4	5.1	4.8	4.5
6.4688	6.79224	7.1156	7.43912	7.7625	8.086	6.14536	5.8219	5.49848	5.1750	4.8516
-4.5342	-4.76091	4.9876	-5.21433	5.4410	-5.66775	-4.30749	4.0807	-3.85407	3.6273	-3.40065
11.217	-11.7782	-12.339	-12.8999	13.460	-14.0216	-10.6564	10.095	-9.53471	8.9738	-8.41298
14.996	-15.7464	16.496	-17.2461	17.995	-18.7458	-14.2468	13.496	-12.7471	11.997	-11.2475
2.6548	2.78754	2.9202	3.05302	3.1857	3.3185	2.52206	2.3893	2.25658	2.1238	1.9911
1.1105	1.16602	1.2215	1.27707	1.3326	1.38812	1.05497	0.9994	0.94392	0.8884	0.83287
0.1	0.105	0.11	0.115	0.12	0.125	0.095	0.09	0.085	0.08	0.075
-0.3695	-0.38798	0.4064	-0.42493	-0.4434	-0.46188	-0.35103	0.3325	-0.31408	-0.2956	-0.27713
-0.5392	-0.56616	0.5931	-0.62008	0.6470	-0.674	-0.51224	0.4852	-0.45832	0.4313	-0.4044

3. Result and Discussion

The wind speed of the horizontal axis wind turbine are calculated by using rated power and different twist distribution range and are listed in table 3

Table 3. Wind Speed With Different Twist Range

S. No	Twist Distribution Range	Power (kW)	Wind Speed (m/s)
1	5	1000	11.53787888
2	10	1000	10.936520672
3	15	1000	11.654422208
4	20	1000	11.711732736
5	25	1000	11.771412576
6	-5	1000	11.360895744
7	-10	1000	11.274527616
8	-15	1000	11.189545312
9	-20	1000	11.25110272
10	-25	1000	11.271711264

3.1 Analytic performance for chord distribution

The change in chord distribution for step of 5% increase in twist values from the 5 to 25% in twist distribution are shown in figure 2. A chord direction is perpendicular to the span direction and lies in the plane extending through the lead edge and the trail edge. Shoulder is the point where chord is maximum and it is minimum at the tip of the blade. Here Stresses are maximum at the blade root so that the blade root is the thickest portion of the blade. As shown in the above figure 2. The chord distribution would remain constant for various changes in twist distribution and it would change only if there is a change in rotor diameter. As we move along the radial position the chord length is maximum at the radial position of 20ft and the chord length eventually decreases with the increase in radial position. The chord length decreases with increase in radial position.

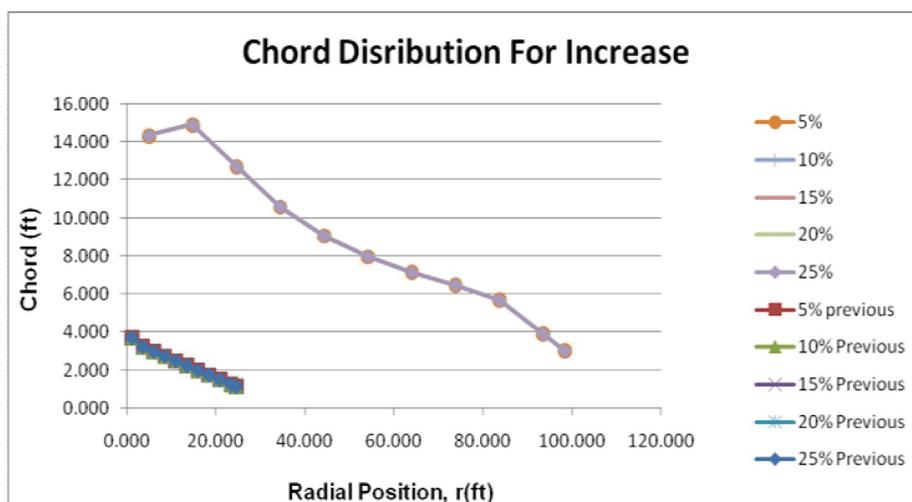


Figure 2. Chord distribution for increase range

It shows that a constant chord distribution been maintained constantly along the radial position of the blade because chord length of the blade depends on the rotor diameter. The above graph shows chord distribution with respect radial distribution. Chord distribution for step of 5% decreases in twist values from the -5 to -25% in twist distribution. For each graph the chord distribution remains the same as the chord distribution only changes only if the rotor diameter changes. The chord length decreases with increase in radial position.

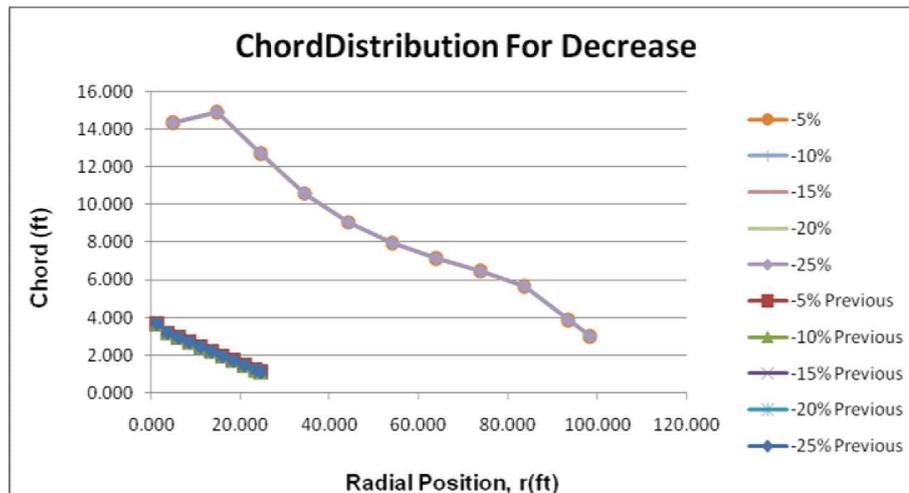


Figure 3. Chord distribution for increase range

3.2 Analytic Performance for Twist Distribution

The twist distribution for increase in each 5% of twist values is shown in figure 4. It is observed that twist angle increases and it reaches a maximum twist of 8° then it decreases reaches a negative twist of -19° it then further increases and it reaches a positive twist of 3° after that it eventually reaches a constant and the twist reaches 0° which indicates that the twist is maximum at the root of the blade and it decreases and becomes 0° and the blade tip.

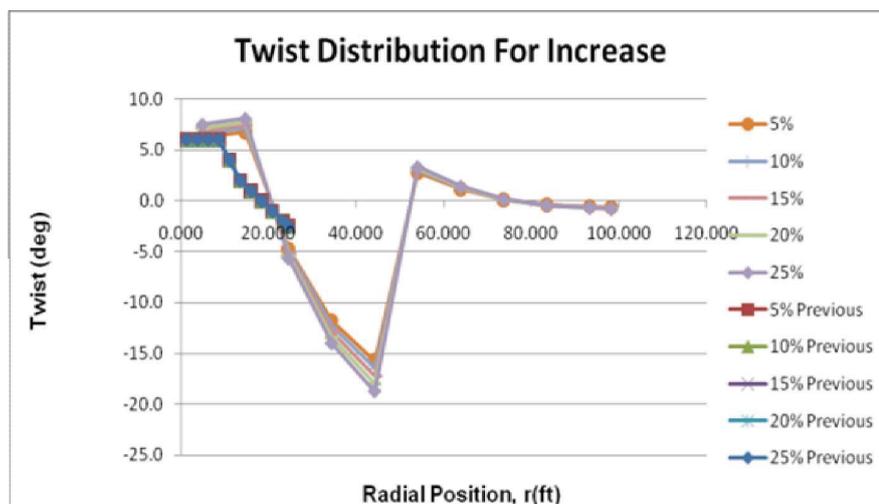


Figure 4. Chord distribution for increase range

It is observed that in the figure 5 the twist distribution reaches a maximum degree of 6° for the -5% twist distribution of radial position 20ft. It decreases and it reaches a negative twist of -15° with the radial position 41ft it further increases and reaches a positive twist of 3° and it decreases and reaches constant twist of 0° at radial position of 80 ft. For the design of the new twist distribution as shown in figure 5, ten different distributions have been analyzed. All of them have been chosen considering it does not differ much from the original.

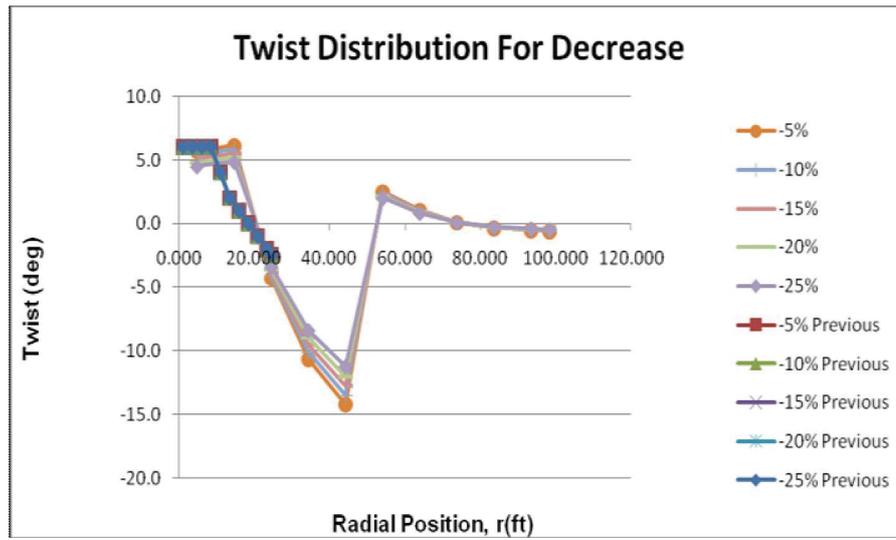


Figure 5. Chord distribution for increase range

The design of an aerodynamic efficient blade aim is to have the largest twist and chord at the root, and then it decreases toward the tip. And other considerations like inner part of the blade are only designed for some starting torque and efficiency, because the outer blade generates most of the power. Therefore, that is the part of the blade that must be aerodynamically efficient.”To achieve that, it has been chosen three different twist distribution that are closed to the one currently being use. By changing the twist distribution the angle of attack is affected, as it has been mention before and the lift-to-drag coefficient too. Twisting the blade along the length allowed the angle of attack to be optimized, depending on the relative wind that a given portion of the blade. Also, by changing the angle of attack, the lift is maximized, increasing the rotational moment and at last, the power output.

3.3 Analytic performance for Power coefficient

The power coefficient distribution for increase in 5% each of twist values is shown in figure. 6. It is observed that coefficient of power starts from zero value, then reaches the peak value of 0.403 at a wind speed of 3 m/s and decreases to negative value of -0.600 at a wind speed of 6 m/s. The coefficient of power decreases with increase in wind speed, because the turbine extracts energy by slowing down the wind with the blade therefore as the speed increases the blade can't slow the wind speed after certain limit. After a certain increase in wind speed the coefficients of power decreases.

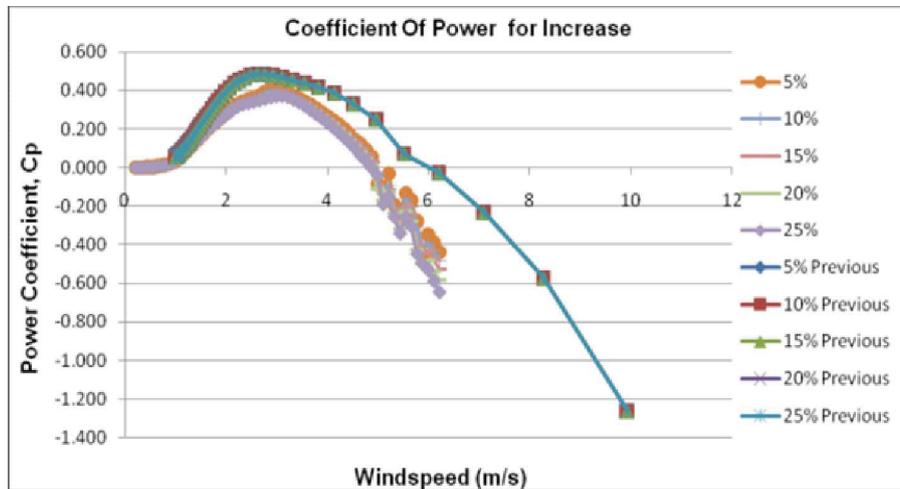


Figure 6. Power of Coefficients for increasing twist

The coefficient of power starts from 0 it increases with an increase in wind speed and it reaches a maximum of 0.400 for a wind speed of 3 m/s as shown in figure 7. It is observed that as the wind speed increases the coefficient of power decreases and reaches a value of -0.400 for a wind speed of 7m/s. This shows that the coefficient of power decreases with an increase in wind speed making it less efficient.

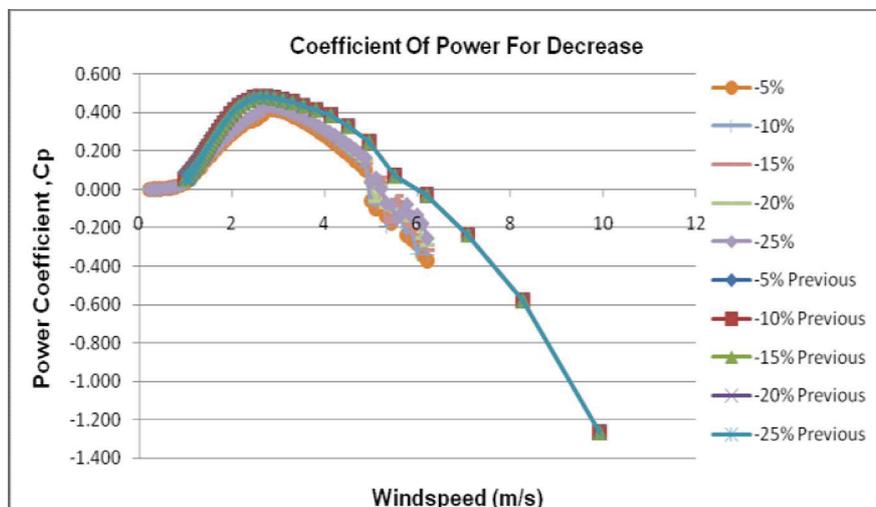


Figure 7. Power of Coefficients for decreasing twist

3.4 Analytic performance for Power

As a wind speed increases the power increase gradually as shown in figure 8. Also shows that the rated power remains constant and will not increase even with the increase in wind speed. It also shows that the 10% increase in twist distribution gives an optimum performance as the rated power is obtained at wind speed of 9 m/s and same trend is follow even decreasing the twist as shown in figure 9.

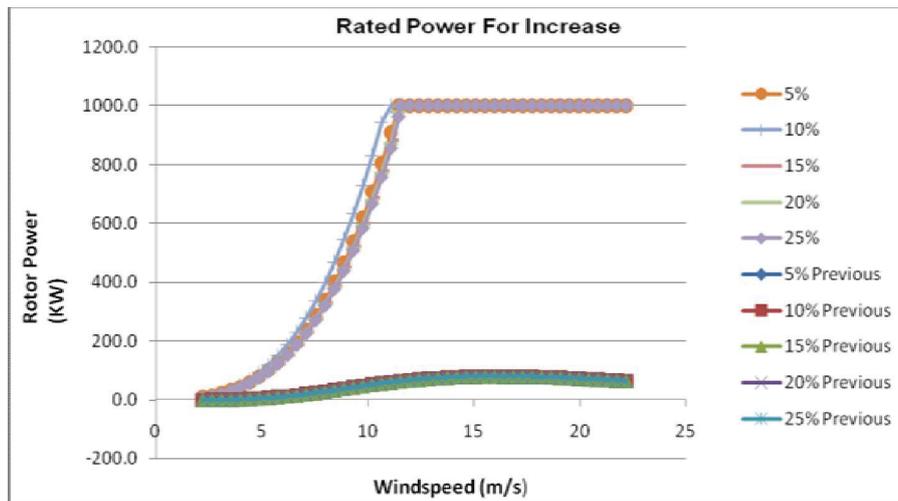


Figure 8. Rated power for increasing twist

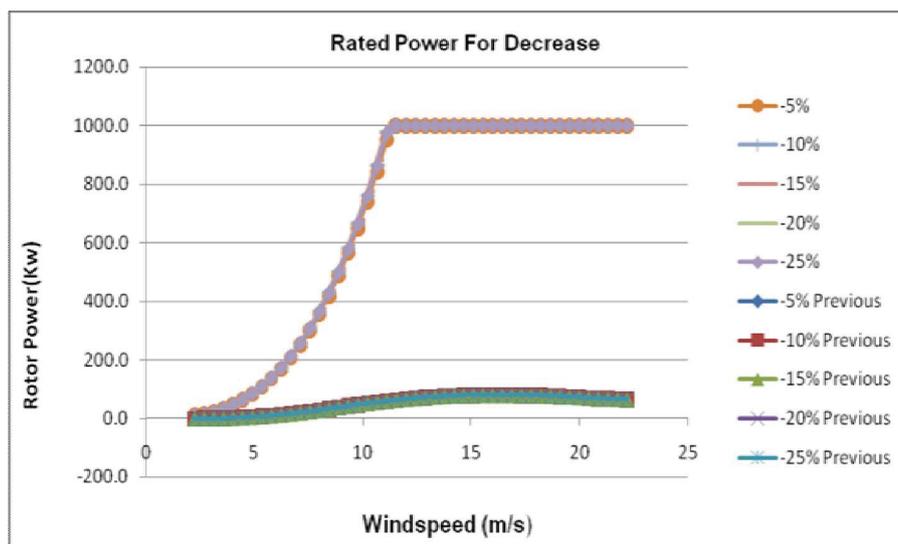


Figure 9. Rated power for decreasing twist

The 10% increase the rated power of 1000 KW is attained at a wind speed of 10.93 m/s. Hence the rated power was attained for 10% increase. The main objective is to attain rated power at rated wind speed for low wind condition by changing the twist distribution of wind turbine blade with respect to chord. Hence twist distribution has been evaluated in PROPID tool on the basis of BEMT. The best value will be selected to suit for low wind condition. The project deals with aerodynamic design of horizontal axis wind turbine with a specification of rotor diameter of 60m, hub height of 70m and power generation of 1000KW. It shows that 10% change in twist distribution gives the desired rated power at the lowest wind speed as shown in figure 9. The graphs were plotted based on the data from Win Wind brochure, default as given in PROPID and the value obtained for change in 10% of twist as shown in figure 10.

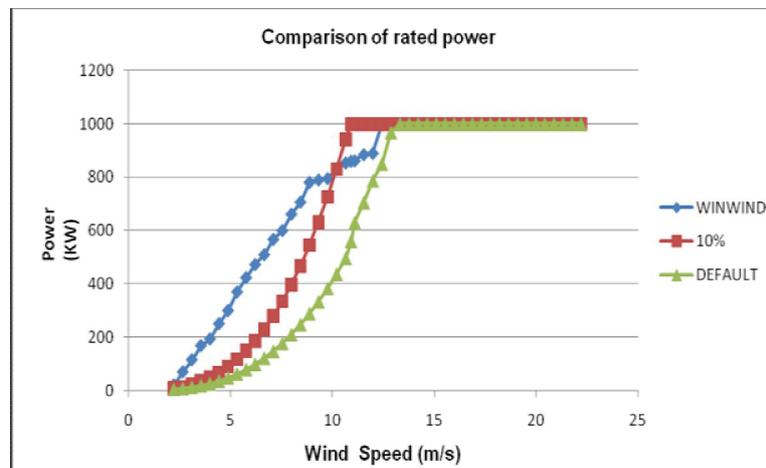


Figure 10. Comparison of rated power

4. Conclusion

The present works are carried out to evaluate the blade profiles like root, mid and tip section of blades and also the computational work has been carried out to analyze the output parameters for the different range of chord and twist distribution. The optimized value for the 10% increase in twist and a rated power of 1000 KW has been obtained for a wind speed of 9 m/s which can be suited for low wind locations like India and also the calculated wind turbine of rated wind speed 10.93 m/s for the same rated power of 1000 KW.

References

- [1] Badr M A and Maalawi K Y, 2003, A practical approach for selecting optimum wind rotors Renewable Energy , Vol 28(5), pp 803-822.
- [2] Juan Mendez and David Greiner Wind Blade Chord and Twist Angle Optimization by Using Genetic Algorithms Institute of Intelligent Systems and Numerical Applications in Engineering Univ., Spain.
- [3] Djavareshkian M H, Latifi Bidarouni A and Saber M R, 2013, New Approach To High-Fidelity Aerodynamic Design Optimization Of A Wind Turbine Blade, International Journal of Renewable Energy Research, Vol.3, No.3, pp. 725-735.
- [4] National Renewable Energy Laboratory, "PROPID", "Air Foil Prep Tools".
- [5] Nitin Tenguria, N. D. Mittal and Siraj Ahmed, Evaluation Of Performance Of Horizontal Axis Wind Turbine Blades Based On Optimal Rotor Theory Journal of Urban and Environmental Engineering, Vol.5, No.1, pp 15-23.
- [6] Peter J. Schubel and Richard J. Crossley, 2012, Wind Turbine Blade Design', Energies, Vol. 5, pp 3425-3449.
- [7] Sandip. A. Kale and Ravindra N. Varma, 2014, Aerodynamic Design Of A Horizontal Axis Micro Wind Turbine Blade Using NACA 4412 Profile, International Journal of Renewable Energy Research , Vol.4 (1), pp 69-72.

- [8] Xu Baoqing and Tian De, 2012, Simulation and Test of the Blade Models Output Characteristics of Wind Turbine”, Energy Procedia, Vol.17, pp 1201 –1208.